Introduced Taxa in Disturbed Ecosystems

by

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ABSTRACT

In the literature, introduced taxa are assumed to be present, more abundant, and occupy greater physical space in portions of ecosystems disturbed by human activity. This study tested this principle in two sites, Short Hills Provincial Park ("SH") and Backus Woods ("BW"). Spatial distribution of introduced taxa of vegetation, isopods, and earthworms was determined with the runs test along 300m transects encompassing gradients of anthropogenic disturbance severity. The hypothesis was that introduced taxa would be aggregated along these transects; the null hypothesis was that they would not be aggregated.

The null hypothesis was rejected for the introduced taxa as a unit, and vegetation and earthworms individually. Introduced taxa were aggregated along 53.33% (N=30) and 57.14% (N=21) of the transects in SH and BW (respectively). Introduced vegetation (90.00%, N=10 and 100.00%, N=7) and earthworms (50.00%, N=10 and 50.00%, N=8) were also significantly aggregated within the sites. Introduced isopods, however, were not significantly aggregated at either place (20.00%, N=10 and 16.67%, N=6).

This study demonstrated that introduced taxa are aggregated within ecosystems disturbed by human activity. However, since introduced isopods were not significantly aggregated it was also shown that taxa respond differently.

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INTRODUCTION

Ecosystem disturbance is a type of ecosystem "adversity" (Middleton,1987) that can be defined in terms of its intensity, duration, and frequency of occurence (O'Neill,et al.1987; Harmon,et al.1983). Disturbance can be catastrophic and readily detectable (eg., fire, hurricanes, landslides, etc.) or more chronic and subtle (eg., global warming of air temperature). Ecosystem disturbance can be natural (eg., drought, lightning fires, glaciation, etc.) or anthropogenic (eg., irrigation, timber cutting, acid deposition, etc.). Anthropogenic disturbance includes both natural disturbance suppression and physical destruction of communities (White,1979).

Natural disturbances are intrinsic components of ecosystem dynamics that create the heterogenous landscapes that are the "environmental setting in evolution" (White,1979). Natural disturbances affect species diversity, community structure, nutrient cycling, water balance, and energetics of ecosystems (vanDobben and Lowe-McConnell,1975; White,1979; Lorimer,1980; Mooney and Godron,1983; Foster,1988; Goldberg and Gross,1988). Ecosystem response to disturbance is dependent upon the temporal properties of the perturbation (O'Neill,et al.1987). Any given disturbance will differentially affect the different hierarchial levels of an ecosystem's organization

(O'Neill, et al.1987; Pickett, et al.1989). As stated by Orians (1986): "One organism's pollutants are another's nutrients". As long as the perturbation does not occur at a scale larger than the entire system, there may not be a total disruption of function at the higher level of organization (O'Neill,et al.1987).

Based on her observations on wildlife, Freemark (1987; pg 77) stated: "Disturbance may stimulate individuals to change their location or alter reproductive output, or may modify relative fitness of phenotypes. Individual responses or modified relative fitness collectively produce changes recognizable at population, species-assemblage, ecosystem and landscape scales. At the population scale, attributes such as density, spatial distribution, mortality rate, reproductive rate, genetics, and extinction probabilities may change. At the assemblage scale, changes may occur in species composition, relative abundance or trophic structure because of differences in the response of species to disturbances. For ecosystems, functional rate processes such as energy flow and nutrient cycling may also be altered as a result of the responses of component species. Spatial and temporal attributes may also be changed by disturbance effects accumulated over all other scales".

The ecological consequences of many anthropogenic disturbances are similar to natural disturbances (White,1979; Bazzaz,1983; Harmon,et al.1983). However, whereas natural disturbances are basically stochastic, anthropogenic disturbances are often based on management decisions that are, in turn, directed by human social factors (Reiners,1983). Odum (1969) and Jacobs (1975) suggested that anthropogenic disturbances reset succession to earlier, less mature stages which are dependent upon the severity of the perturbations. On the other hand, Lorimer (1980) argued that anthropogenic disturbance (eg., selective cutting of shade intolerant trees in forests) may "hasten succession". Humans also tend to alter further subsequent natural patterns of disturbance and successional development (Chapin,1983). Again, how and to what intensity disturbance patterns are managed depends on society's intentions for an ecosystem.

Disturbed ecosystems are potential experimental testing grounds for gaining insight into ecosystem properties (Middleton and Merriam, 1985). Trends expected in anthropogenically disturbed ecosystems have been discussed by Schindler (1987) and Odum (1985). The effects of anthropogenic disturbance on species compositions (Rogers,1978; Clout and Gaze,1984; Holmes,et al.1987) and the recovery times of disturbed ecosystems (Horne and Gwalter,1987) have also been examined. One fact is certain: anthropogenic disturbance is rapidly expanding, in some cases to global proportions (eg., ozone depletion, the greenhouse effect, etc.). This fact alone necessitates development of an understanding of disturbance effects on ecosystems.

The focus of this study was an observation made early by ecologists- the correlation between anthropogenic ecosystem disturbance and the presence of introduced taxa. Tansley (1939) noted from his observations of invasions in Irish oakwoods: "if this displacement of Ilex sp by Rhododendron sp is really progressive it is an interesting example of an apparently rare phenomenon, the successful invasion of an undisturbed community by an exotic species." In his classical work, "The Ecology of Invasions by Plants and Animals", Elton (1958) wrote: "It will be noticed that invasions most often come to cultivated land, or to land much modified by human practice." More recently, Williamson and Brown (1986) summarized current knowledge regarding introduced invasions by stating: "With regards to habitats, the most commmonly expressed view is that disturbance, particularly man-made disturbance, is needed for a new species to invade."

Case histories of invading introduced taxa supporting the above observations are abundant (Elton,1958; Baker,1986; Orians,1986; Pimmentel,1986; Mack,1986; Mooney,et al.1986), however, little hypothesis testing has been carried out in ecological literature.

Concern for and the state of knowledge of the ecology of biological invasions have been consolidated in volumes edited by Groves and Burdon (1986), Mooney and Drake (1986), Kornberg and Williamson (1987), Duffey (1988), and Drake,et al.(1989). From these works it is apparent that although obvious advances have been made in the understanding of biological invasions, many important questions are yet to be answered. The need to understand potential effects of introduced organisms is especially apparent in the fields of biological control (see van den Bosch,et al.1982) and the development and release of recombinant DNA organisms (Levin,1988; Williamson,1988; Simonsen and Levin,1988; Ellstrand,1988). It has been said that biological invasions into new habitats are "some of the most important field experiments ever carried out in ecology" (Crawley,1986).

With the above themes in mind the objective of this study was to test quantitatively the ecological principle infered by Tansley (1939), Elton (1958), and Williamson and Brown (1986) that introduced taxa are more "successful" in the portions of ecosystems that are more disturbed by human activity than in the less disturbed portions of those ecosystems. The hypothesis of this study is one of the prerequisites of the principle stated above. The hypothesis was that the "success" of introduced taxa is spatially aggregated in ecosystems that have been exposed to gradients of anthropogenic disturbance severity; the null hypothesis was that the "success" of introduced taxa is not aggregated within such ecosystems. Data that support the hypothesis are consistent with the principle stated above, whereas support of the null hypothesis weakens this ecological principle.

"Success" of introduced taxa in this study implied their survival in an ecosystem. Quite simply, if introduced taxa were present in the ecosystems, they were "successful" (in turn, the more space they occupied, the more "successful" they were). When the field data were available, quantitative measures were designed to reflect both the level of abundance of introduced taxa (eg., "total numbers of introduced taxa in sampling plots") and the amount of physical space they occupied (eg., "coverage of introduced taxa in sampling plots"). The calculations of these measures are detailed in the methods (pgs 22-23).

It is important at this point that a clear distinction be made between the significance of aggregation of individuals of a species and that of species assemblages as it relates to this study. Students of population and community ecology are aware that, in general, populations of species tend to aggregate in a landscape wherever the environmental requirements for their survival are met (particularly where conditions for their survival are optimum) (Whittaker,1956;1966; Kershaw,1964; Hutchinson,1978; Pielou,1976; Greig-Smith,1979;1986). Random and regular patterns are "comparatively uncommon" (Pielou,1976). The objective of this study, however, was not to look at the distribution of individual introduced species (as suggested above, these distributions would likely be aggregated), but rather it was to look for non-randomness at a higher level of ecosystem organization, the taxon assemblage, introduced taxa.

Natural disturbance regimes (the sum of disturbances operating in a given landscape; White,1979) have been shown to induce non-randomness (spatial aggregation) of several species assemblages (eg., chaparral, Parsons,1976; North American temperate forests, Harmon, et al.1983; Runkle,1985; tropical rainforests and coral reefs, Connell,1978). The coexistence of the species in such assemblages has been partially attributed to their common ability to exploit the conditions instigated by disturbance (Marquis,1975; Cook and Lyons,1983; Karr and Freemark,1983; Harmon, et al.1983; Denslow,1985). Disturbance is needed for the survival of some species (Levin and Paine,1974; White,1979; Karr and Freemark,1983). The factors influencing disturbance-mediated coexistence of species (eg., frequency, spatial extent, severity, etc.) are reviewed by Denslow (1985).

Anthropogenic disturbance regimes, when similar in character to natural disturbance, can initiate the same basic species assemblages as natural disturbance. Logging in Canadian boreal forest, for example, can initiate successional patterns similar to those following spruce budworm outbreaks (Denslow,1985). At some point, however, when anthropogenic disturbance no longer mimics natural disturbance, species assemblages can change dramatically from pre-disturbance conditions. For instance, Madnay and West (1983) found that the conversion of a ponderosa-pine savanna to forest in Utah was primarily the result of heavy livestock grazing and, secondarily, fire suppression.

By challenging the principle of differential "success" of introduced taxa in disturbed and undisturbed portions of ecosystems, in essence, this study was also a test of whether anthropogenic disturbance initiates the aggregation of introduced taxa. The logic used was as follows: the transects sampled in this study encompassed continua of anthropogenic disturbance severity (from more disturbed to less disturbed), therefore, if greater "success" of introduced taxa was found to be aggregated along these transects, then it followed that anthropogenic disturbance could be inducing the spatial aggregation of introduced taxon "success".

Introduced taxa are defined as those that have become established in North America after having been introduced (intentionally and accidentally) by human agency from other continents. These introductions have been relatively recent (within the last 200 years). Based on preliminary sampling, three groups of organisms were chosen for study: terrestrial vegetation, isopods, and earthworms. The runs test (Pielou,1969;1976;1979; Sokal and Rolf,1981) was used to determine whether aggregation of greater "success" (as opposed to lesser) of the introduced taxa of these three groups was occuring along transects set out within two study sites in southern Ontario.

An auxiliary study was conducted to determine the most reliable measures of introduced taxon "success" of those initially designed in the main study. Experiments to assess both repeatability of the field techniques used to collect vegetation field data and seasonal variability of the results obtained for all groups were carried out in the auxiliary study. In addition, potential effects of the steepness of the disturbance gradients of the transects on the distributions of introduced taxon "success" were examined.

The discussion reflects upon both the results of this study and their significance in light of present concerns regarding introduced taxa in ecosystems (particularly "pristine" ecosystems) and the intentional releases of introduced taxa (eg., biological control and DNA-engineered organisms).

SITE DESCRIPTIONS

No areas of the region of study (southern Ontario) are untouched by some sort of human-induced ecosystem disturbance, including pollution (Borman,1982). The degree of human impact varies widely. The two sites chosen for this study contained ecosystems that have been exposed to a wide range of anthropogenic severities within the distance of hundreds of metres. Severity represents "the impact of the disturbance on the community, thus is defined in terms of change in community properties such as basal area, density, species composition and biomass" (Harmon,et al.1983).

In the sites chosen for this study, extremes of ecosystem disturbance severity were recognized on the basis of vegetational composition. Grime (1983; pg 40) wrote: "With respect to the intensity of damage experienced by (the) vegetation, a continuous range of plant habitats may be recognized. One end of the spectrum is represented by relatively undisturbed habitats such as mature temperate forests (Odum,1969). At the other extreme there are habitats such as arable fields". In this study, open fields defined the more disturbed extreme of the ecosystems studied whereas closed canopy forests defined the less disturbed extreme. Gradients of disturbance severity (Harmon,et al.1983) lay between the open fields and their adjacent forests.

The first field season (1987) was spent at Short Hills Provincial Park (Thorold, Ontario; lat. 43° 6'N, long. 79° 17'W). The second field season (1988) was spent at Backus Woods and the adjacent Backus Woods Conservation Area (Port Rowan, Ontario; lat. 42° 39'N, long. 80° 28' 30''W).

1) Short Hills Provincial Park

Short Hills Provincial Park is located within a re-entrant valley cut into the Niagara Escarpment (see Chapman and Putman,1973 for a description of this landform) by ancient rivers (Ontario Ministry of Natural Resources,1975). Both ancient and more recent stream development have further dissected the Short Hills Provincial Park area into the present short hill topography (Ontario Ministry of Natural Resources,1975).

Agricultural and urban development of Short Hills Provincial Park and its surrounding area by European settlers began in the 1780's (Ontario Ministry of Natural Resources,1975). Despite over 200 years of European influence a number of relatively undisturbed areas have been maintained within the park. Most of these relatively undisturbed areas are in stream valleys where rugged topographic conditions prevented clearing and utilization of the land for agriculture. The resulting vegetation pattern in the park is a mosaic of open areas on hilltops and wooded slopes and valleys.

Short Hills Provincial Park is 40 to 50% forested

(Ontario Minstry of Natural Resources,1975). These forests are part of both the Niagara Region of the Deciduous Forest Region of Canada (Rowe, 1959) and the Carolinian Floral Region of Canada (Dice,1943; Scoggan,1978). Some of the remaining open areas are being farmed at this time for field crops such as corn and wheat. Other open areas are abandoned crop lands and pastures. These abandoned (old) fields are predominantely Solidago sp, Aster sp, and grasses (pers. obs.). In an old field complex within the same region, Maycock and Guzikowa (1984) found 51.7% native plants (n=118) and suggested that the average percentage of introduced species in Ontario's old fields is 20%.

Hereafter, the Short Hills Provincial Park site will be refered to as "Short Hills".

2) Backus Woods and Backus Woods Conservation Area

Backus Woods and the Backus Woods Conservation Area are situated on the Norfolk Sand Plain of southwestern Ontario (Chapman and Putman,1973). These sands have been eroded into a complicated series of dune formations (Presant and Acton,1986).

Backus Woods is a 260 ha tract of contiguous forest, one of the largest areas of contiguous forest in southern Ontario (Long Point Region Conservation Authority,1979). The 160ha Backus Woods Conservation Area is south of Backus Woods (separated by a paved concession road).

European settlement in the area of Backus Woods and Backus Woods Conservation Area began in the 1790's (Long Point Region Conservation Authority,1978). Due to the efforts of its first European owner, John Backhouse, Backus Woods has been left relatively undisturbed. About 75% of the 260 ha area of Backus Woods is old growth forest (Varga,1986).

Backus Woods Conservation Area includes the site of the Backus homestead and two areas that have remained relatively undisturbed: a large woodlot in the northwest corner of the park and the floodplains of Dedrick and Mud Creeks (Long Point Region Conservation Authority,1978). It was in these two areas where sampling for this study was restricted.

Backus Woods and the Backus Woods Conservation Area are also part of the Niagara Region of the Deciduous Forest Region of Canada (Rowe,1959) and the Carolinian Floral Region of Canada (Dice,1943; Scoggan,1978).

The open fields adjacent to the forests of both Backus Woods and Backus Woods Conservation Area were either old fields (of variable age) or were being used presently for agriculture (tobacco and field crop production). The old fields consisted mostly of <u>Solidago</u> sp, <u>Aster</u> sp, <u>Erigeron canadensis</u>, and grasses (pers. obs.).

Hereafter, the Backus Woods/Backus Woods Conservation Area site will be refered to as simply, "Backus Woods".

Climate of Southern Ontario

Southern Ontario has a moderate climate with warm summers and mild winters. The start of the growing season (ie., the average date when temperature rises above 6°C) is between April 5 and 10 in this region. The end of the growing season is between November 5 and 10. The average frost-free period (ie., when daily temperatures > 0°C) ranges from May 5-10 to October 10-15 (approximately 150-160 days) (Brown,et al.1980).

Mean annual precipitation at the study sites is between 85 and 90cm (Brown,et al.1980).

METHODS

Organisms Studied

Several groups of organisms were initially considered for this study. Primarily, those chosen had to have introduced taxa in the region of study. In addition, individuals of these groups had to be potentially present in both open fields and forests so as to not induce an obvious tendency for aggregation in the data prior to sampling and analyses. And finally, because of the scale at which this study was run (ie., hundreds of metres) organisms with small "home" ranges were preferable to highly mobile species. At the scale used, highly mobile species would bias the data towards daily (if not momentary) variability and, in turn, increased randomness. Based on preliminary sampling, the groups chosen were terrestrial vegetation, isopods, and earthworms. The taxonomic categories sampled were as follows:

1) Vegetation (from Gleason and Cronquist,1963)

    Division Pteridophyta

    Division Spermatophyta

    (see Appendices 2 and 3 for the lower ranking taxonomic categories sampled)

2) Isopods (from Judd,1965; Barnes,1984)

    Phylum Crustacea

Class Malacostraca

Order Isopoda

Sub-order Oniscoida

Family Oniscidae

(see Appendices 2 and 3 for the species sampled)

3) Earthworms (from Barnes,1984)

Phylum Annelida

Class Oligochaeta

Order Haplotaxida

Sub-order Lumbricina

Family Lumbricidae

Data were also collected for terrestrial snails and slugs (Mollusca, Gastropoda, Pulmonata) but were not analyzed at this time due to taxonomic difficulties.

Both vegetation and isopods have introduced and native species in the region of study. The majority of the literature on earthworm origins in the glaciated portions of North America (including southern Ontario) suggest that all of the terrestrial earthworms in these areas were introduced with Europeans during the time of European settlement (Gates,1929; 1954;1966;1976;1978;1979;1982; Reynolds,1975a;1975b;1976; 1977). This is known as the "Post Quaternary Introduction Theory" of North American earthworm origins (Reynolds,1975a). Significant contrary evidence to this viewpoint, however, is given by Schwert (1979) and McKay-Fender and Fender (1982). Arguments against the validity of the Post Quaternary Introduction Theory include Omodeo (1963) and Ball (1975).

Of the 19 species of earthworms found in Ontario, 18 are of the family Lumbricidae which is considered to be endemic to Europe (Reynolds,1977). The remaining native species of earthworm that has been recorded within Ontario is an aquatic species (*Sparganophilus eiseni*) (Reynolds,1977). Only terrestrial species were sampled in this study. Therefore, based on the present weighting of evidence regarding the origin of earthworms in North America, those encountered in this study were considered to be all introduced species.

Transects

Transects 300m in length were randomly placed throughout Short Hills and Backus Woods. The transects were subdivided into 5m sections within each of which a circular sampling plot ($0.6m^2$) was randomly placed. Round sample plots were used to reduce edge effects and the size was based on the ability to sample each plot within a desirable time period (20 minutes to 1 hour) and would encompass all of the organisms chosen for study. The objective was to minimize temporal variation of species compostion and abundance of species during the sampling periods of the transects (transects were generally sampled within one week). Sampling occured from 87 06 12 to 87 09 20 (Short Hills) and from 88 05 31 to 88 09 06 (Backus Woods). The sampling dates and periods required for completion of all 18 transects are listed in Tables 1 and 2 (pg 19).

Only those random transects that traversed both portions of forests and open fields were sampled. To reiterate, forests and open fields were used as guidelines to recognize disturbance severity extremes. By traversing forests and fields the transects encompassed the gradients of disturbance severities essential for this study, that is, the more disturbed extreme (open fields) to the less disturbed extreme (forests). In addition, of the 60 plots of each suitable transect, at least 15 plots were located in forest and another 15 of each were located in open field.

Table 1: Sampling dates and sampling period (days) for transects studied in SHORT HILLS PROVINCIAL PARK.

Transect	Sampling period	Days
1	87 06 12 - 87 06 30	19
2	87 07 06 - 87 07 09	4
3	87 07 13 - 87 07 17	5
4	87 07 20 - 87 07 24	5
5	87 08 05 - 87 08 07	3
6	87 08 10 - 87 08 12	3
7	87 08 20 - 87 08 24	5
8	87 08 29 - 87 09 03	6
9	87 09 09 - 87 09 20	12
9'	88 06 15 - 88 06 23	9

Table 2: Sampling dates and sampling period (days) for transects studied in BACKUS WOODS.

Transect	Sampling period	Days
1	88 05 31 - 88 06 08	9
2	88 07 20 - 88 07 22	3
3	88 08 06 - 88 08 09	4
4	88 08 09 - 88 08 11	6
5	88 08 11 - 88 08 17	7
6	88 08 29 - 88 08 30	2
7	88 08 31 - 88 09 01	2
8	88 09 01 - 88 09 06	3

Field Data

The data collected for live plants were: taxa in and cover in each sample plot, maximum heights of each taxon, and cover (percentage of plot area) of each taxon.

Identifications and origins (ie., native and introduced) of plant taxa were determined from information in Gleason and Cronquist (1963), Petrides (1986), Peterson and McKenny (1968), and Hosie (1979). Plant identifications were made to the level of species when possible or to genus when it was known that the genus of an individual was known to be of one origin (ie., native or introduced).

Total numbers of taxa and numbers of native and introduced taxa were tallied for each plot for use in calculations of introduced taxon "success". Maximum height was the height above ground level of the tallest individual of each plant taxon in each plot. Tree heights were measured via an optical height meter (SUUNTO Height Meter, model PM-5/1520). Accuracy of tree heights was +/- 1-2% (SUUNTO Co.). The cover of each plant taxon was visually estimated as a percentage of sampling plot area (Kershaw, 1964). The cover classes were: 1, 5, 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100%.

Terrestrial isopods were found by hand searching of leaf litter, logs, mosses, grass litter, etc. Data collected for isopods were the numbers of each species found in each plot. Large numbers of some of the small, fast-moving species were estimated as >30, >50 or >100 per plot. Identifications and origins of the isopods encountered were determined with information from Walker (1927; 1928), Judd (1963;1965;1976; personal communication), Muchmore (1957), Sutton (1980) and Rafi and Thurston (1982).

Since the earthworms encountered in this study were all considered to be introduced species (according to most of the literature regarding earthworm origins in Canada), earthworm data collection was the recording of their presence in sampling plots (this eliminated the need for extensive identification of individuals). Earthworm presence in sampling plots was noted by: evidence of surface casts , presence of individuals on the soil surface, and individuals seen in soil cores (8cm diameter, 15cm depth). Earthworms were found on the soil surface by hand searching amongst and below leaf litter, logs, stones, etc. Soil cores were dug with a hand held trowel and examined by manually sifting through handfuls of soil. Only active or aestivating earthworms were noted (not cocoons). Cores were dug in all sampling plots at Short Hills. In Backus Woods, however, cores were dug only where no surface casts or individuals were found on the surface.

"Success" of Introduced Taxa

The field data collected were used to calculate quantitative measures of "success" for the introduced taxa examined. As previously discussed, these measures reflected the level of abundance of introduced taxa in the ecosystems studied. For each sampling plot, candidate measures of "success" for introduced vegetation were calculated as:

i) Presence of introduced taxa

ii) Total number of introduced taxa

iii) % number of introduced taxa=

total number of introduced taxa/
total number of plant taxa in that sampling plot
(X 100)

iv) Total cover of introduced taxa

v) % cover of introduced taxa=

total cover of introduced taxa/
total cover of all plant taxa in that sampling plot
(X 100)

vi) Total "volume" of introduced taxa=

the sum of maximum heights X covers of introduced taxa in that sampling plot

vii) % "volume" of introduced taxa=

total "volume" of introduced taxa/
total "volume" of all plant taxa in that sampling

plot

(X 100)

"Success" for the introduced invertebrate taxa was defined as presence of introduced isopods in sampling plots and presence of earthworms in sampling plots.

The following auxiliary study was conducted to determine the most reliable measures of introduced taxon "success" from the candidate measures listed above.

Auxiliary Study:

Test of repeatability of the methods used in the main study

This auxiliary study consisted of the following two distinct experiments.

A) Repeatability of Field Techniques for Vegetation Data Collection

The objective of this component of the auxiliary study was to determine the most repeatable methods of collection of vegetation field data that, in turn, would yield the most reliable measures of introduced vegetation "success" from the candidate measures of "success" proposed in the main study. The methods examined were the recording of: cover of plant taxa in sampling plots, taxon presence in sampling plots and, total numbers of taxa in sampling plots.

The site chosen for Part A) was in a rural portion of Welland, Ont (43° 00 N, 79° 14' W). The open field and forest sampled at this site were similar in vegetative compostion to both Short Hills and Backus Woods. Within this site a 40m transect was set out so as to encompass portions of both an open field and a forest. Eight circular sampling plots ($0.6m^2$) were placed randomly within 5m subdivisions of this transect. Plots 1 to 3 were situated in the open field (ie., no tree cover) and plots 4 to 8 were beneath forest cover. The sampling plots were set out for the duration of the sampling period, 88 Ø5 12-15. The vegetation field data collected at the eight sampling plots were the same as those collected in the main study, excluding maximum heights. Care was taken not to disturb the contents of the plots during sampling so as not to influence their subsequent samplings.

In preliminary tests of proposed methods for Part A) memorization of sampling plot contents always occured eventually after numerous samplings of a plot. Techniques that minimized memorization included: leaving the site after one or two transect repetitions and interdispersing the work with other tasks, recording data on cassette tape rather than writing, sampling plots in different orders every repetition of a transect, and minimizing the amount of time spent at a sampling plot (to 5-1Ø minutes). Once memorization of a sampling plot became apparent to the investigator (ie., plot contents began to feel "familiar"), sampling of it was stopped. Plots were sampled 12 to 14 times.

To assess repeatability in the recording of plant cover (recorded as percentage of plot area) arcsin transformations of the cover estimations of each taxon for each plot were first calculated. The % coefficients of variance (%CV) of these arcsin values for each taxon were then calculated and are found in Table 5 (pgs 4Ø-41).

To evaluate repeatability in the recording of presence of plant taxa in the plots, values of % observance were calculated for each of the taxa sampled.

% Observance = number of times a plant taxon was seen /
total number of sampling repetitions
of its plot (N= 12 to 14)
(X 100)

For example, if a taxon was seen every time its plot was sampled, its % observance would equal 100%.

To evaluate the repeatability of the recording of total numbers of plant taxa in plots, the %CV of total numbers of plant taxa observed during each repetition of each plot were calculated. These values are listed in Table 6 (pg 42).

B) Seasonal Variation of the Distributions of Introduced Taxon "Success" of all Groups Studied

The null hypothesis of this test was that the distributions of introduced taxon "success" (as it was defined and analyzed in the main study) would not be affected by the season of sampling of the transects studied. Those measures of introduced taxon "success" designed in the main study that were affected by season of sampling in this test were deemed less reliable measures of "success" than those not affected by season of sampling.

Using the methods of the main study, Transect 9 of Short Hills was sampled at the end of the first field season (87 Ø9 Ø9 to 87 Ø9 2Ø) and was resampled for all groups at the start of the subsequent field season (88 Ø6 15 to 88 Ø6 23). These transects are refered to as Transect 9 (sampled in September) and Transect 9' (sampled in June).

The resulting distribution patterns of all measures of introduced taxon "success" for both Transects 9 and 9' are listed in Table 3 (pgs 34-35). These results were compared qualitatively.

Statistical Analysis- The Runs Test

The runs test is a non-parametric, one-tail test used to analyze the distribution patterns of series of consecutive binary events along linear maps (eg., presence/absence of introduced taxa in plots along transects) (Pielou,1976;1979; Sokal and Rohlf,1981). In this study, the runs test was used to determine whether greater values of introduced taxon "success" were aggregated along the transects sampled. The conceptual framework of the methods used as it relates to the runs test and an example of a runs test analysis is given in Appendix 1 (pgs 104-109).

The candidate measures of introduced taxon "success" were redescribed as binary events for runs test analyses of their transects. These binary events were designed to reflect greater and lesser "success". For example, presence/absence of introduced taxa in sampling plots for all three groups of organisms were analyzed as in the example given in Appendix 1. For the remaining measures of "success", the median values for each measure were determined for each transect. The binary events for these measures were above/at and below the transect median in each sampling plot (see also Sokal and Rohlf,1981).

Runs tests analyses of these binary events were calculated on an NEC/PC-8201A computer using a program written by J.Middleton (Brock University). Each transect yielded one runs test probability value per "success" measure. Probability values $\geq$5% were deemed non-aggregated distributions and values <5% were aggregated distributions. The runs test results for all candidate measures of introduced taxon "success" are listed in Tables 3 and 4 (pgs 34-35 and 38-39, respectively).

In cases in which specimens could not be identified, calculations of "success" and runs test analyses were conducted twice; once as though these individuals were native and once as though they were introduced. When the two approaches to analyses of these unknowns yielded conflicting results (ie., aggregated and non-aggregated distributions) these results are represented as "-" in the tables.

Although isopods were found in both open fields and forests during preliminary sampling (conducted in early May), it became apparent during later sampling that plots without sufficient moisture-holding materials (eg., leaf litter) became uninhabitable for both native and introduced isopods during the dry heat of mid-summer. The datum collected from these sampling plots was "absence" of introduced isopods. Long runs of these uninhabitable sampling plots had the potential of being detected as disjunctions with the runs test which could potentially generate aggregated distributions.

Pielou (1979) discusses a similar situation in which a transect set out perpendicular to a shoreline is sampled for a barnacle. "It is debateable whether a stretch of shore that is uninhabitable by the species should or should not be treated as a 'true' gap. The answer is unavoidably subjective and is influenced by the size of the gap and the dispersal powers of the species" (Pielou,1979).

To test whether long runs of uninhabitable plots for isopods led to a Type I error (ie., rejection of a true null hypothesis), introduced isopod presence along the transects was analyzed by two different approaches. In "Method i)" only sampling plots that contained isopods (native and/or introduced) were analyzed with the runs test (N=11 to 48 sampling plots per transect). This method eliminated all uninhabitable sampling plots from runs test analyses.

In "Method ii)" all sampling plots of the transects (N=60) were included in runs test analyses (as was the approach used for vegetation and earthworms). This method included uninhabitable sampling plots as "absence" of introduced isopods in sampling plots. The results obtained using both methods of analyses are listed together in Tables 11 and 12 (pgs 53 and 54) for comparison.

In Backus Woods, no isopods were found along Transect 2 and only 3 sampling plots of Transect 4 contained isopods. Hence, runs test results of isopod distributions for these two transects are represented in Tables 4, 8, and 12 (pgs 36-37, 47, and 54) as "X". The remaining transects had 11 or more plots containing isopods in Backus Woods.

Potential Effects of Disturbance Gradients of Transects

Consider that the biological signal being detected in this study is the spatial aggregation of "success" of introduced taxa (runs test $P<.05$). It can be assumed that the ecosystems sampled in this study contained variable intensities of aggregation of introduced taxon "success". Aggregation is more intense if a wide range of densities of a factor (in this study, greater introduced taxon "success") is present (and vice versa for less intense) (Pielou,1976). Therefore, the more intense the aggregation of introduced taxon "success" in this study, the stronger the biological signal. In this study, a lack of a signal and, presumably, very weak signals, would be detected as non-aggregated distributions (runs test $P\geq.05$).

The distribution patterns of introduced taxon "success" along the transects in Short Hills were not consistent (ie., all aggregated or all non-aggregated) among transects and among groups (see Table 3 pgs 34-35). One possible reason for this finding was that the disturbance gradients along the transects sampled within Short Hills were not sufficiently steep (or strong) enough to induce consistent, intense aggregation of introduced taxon "success" (or at least as intense as would be consistently detected by the methods used). To test for this condition, Backus Woods was chosen as the study site for the second field season because the disturbance gradients within Backus Woods were steeper than those of Short Hills. Both study sites contained open fields that were very disturbed (presently being farmed) or old fields (abandoned pastures and crop fields). The wider gradient of disturbance severity at Backus Woods was recognized by the fact that the forests of Backus Woods were less disturbed than those of Short Hills. This was deduced from biological and historical information (Ontario Ministry of Natural Resources,1975; Long Point Region Conservation Authority,1979; Varga,1986).

The logic of this test was that if aggregation of introduced taxon "success" was occuring and it was affected by the strength of the disturbance gradients of the transects, then it was suspected that the stronger disturbance gradients of the Backus Woods transects would intensify aggregation and would generate a stronger, consistent signal for detection by the methods used. It still followed that if aggregation was not occuring then non-aggregated distributions of greater introduced taxon "success" would still be detected no matter what disturbance gradient steepness was evident. The hypothesis of this subsidiary test was that the proportion of aggregated transects from Short Hills would be significantly different from that of Backus Woods; the null hypothesis was that these proportions would not be significantly different. Sampling methods used in Short Hills were continued in Backus Woods and the proportions of aggregated and non-aggregated transects from the two sites were compared for significant differences.

RESULTS

1) Distributions of all Measures of Introduced Taxon "Success"-

The runs test results of the transects sampled in Short Hills yielded no consistent distribution patterns (ie., all aggregated or all non-aggregated) or trends of patterns of greater introduced taxon "success" amongst the groups studied or transects (Table 3; pgs 34-35).

The results from Backus Woods indicate consistent aggregation of greater "success" of introduced vegetation using all candidate measures of "success" (Table 4; pgs 36-37). The invertebrates studied in Backus Woods, however, did not demonstrate similar consistency. As in Short Hills, there were also no consistent trends in the distribution patterns of the "success" of the introduced taxa encountered in Backus Woods amongst the three groups of organisms studied (ie., vegetation, isopods, and earthworms).

Table 3: Distribution patterns of all measures of "success" of introduced taxa along transects in SHORT HILLS PROVINCIAL PARK.

N = non-aggregated distribution (runs test $P \geq .05$),
A = aggregated distribution (runs test $P < .05$).

"Success" Measures	Transect									
	1	2	3	4	5	6	7	8	9	9'
A) Introduced Vegetation										
i) Presence	N	N	A	A	A	A	A	A	A	N
ii) Total number*	A	N	A	A	A	A	A	A	A	A
iii) % Total number*	A	N	A	A	A	A	-	A	A	A
iv) Cover*	N	N	-	A	A	A	A	A	A	A
v) % Cover*	A	N	A	A	A	A	A	A	A	N
vi) "Volume"*	A	N	A	A	A	A	A	A	A	N
vii) % "volume"*	A	N	-	-	A	A	A	A	A	N
B) Introduced Isopods										
i) Presence	N	N	N	N	N	N	N	N	A	A
C) Earthworms										
i) Presence	A	A	A	A	N	N	A	N	N	N

Table 3 continued .....

Note:

* indicates the measures that were analyzed with the runs test as the binary events above/at and below the transect medians in 0.6m^2 sampling plots, others were analyzed as presence/absence in sampling plots.

N=60 sampling plots per transect for vegetation and earthworms; N=11 to 48 for isopods.

$\div$ indicates transects in which unidentifiable specimens yielded conflicting runs test results (see text pg 29).

Sampling dates of transects are listed in Table 1 (pg 19).

Table 4: Distribution patterns of all measures of "success" of introduced taxa along transects in BACKUS WOODS.

N = non-aggregated distribution (runs test P≥.05),
A = aggregated distribution (runs test P<.05).

"Success" Measures	Transect							
	1	2	3	4	5	6	7	8
A) Introduced Vegetation								
i) Presence	A	A	A	A	A	A	A	A
ii) Total number*	A	A	A	-	A	A	A	A
iii) % Total number*	A	A	A	-	A	A	A	A
iv) Cover*	A	A	A	-	A	A	A	A
v) % Cover*	A	A	A	-	A	A	A	A
vi) "Volume"*	A	A	A	-	A	A	A	A
vii) % "volume"*	A	A	A	-	A	A	A	A
B) Introduced Isopods								
i) Presence	A	X	N	N	N	N	N	X
C) Earthworms								
i) Presence	A	A	N	N	N	A	A	N

Table 4 continued .....

Note:

* indicates the measures that were analyzed with the runs test as the binary events above/at and below the transect medians in 0.6m^2 sampling plots, others were analyzed as presence/absence in sampling plots.

N=60 sampling plots per transect for vegetation and earthworms; N=11 to 48 for isopods.

- indicates transects in which unidentifiable specimens yielded conflicting runs test results (see text pg 29).

X indicates transects in which <11 plots contained isopods (see text pg 30).

Sampling dates of transects are listed in Table 2 (pg 19).

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2) Results of the Auxiliary Experiment

The results and conclusions of the auxiliary experiment are presented and discussed here in terms of how they directed subsequent procedures in the main study.

A) Repeatability of Field Techniques for Vegetation Data Collection

The % coefficients of variance (%CV) of cover illustrate the potential for large variance in the cover estimations of some plant taxa (Table 5; pgs 40-41). %CV for cover values ranged from 0 to 374.2%. The largest %CV (>300%) corresponded to the taxa with the lowest % observance values (% observance < 10%). Some examples include *Arisaema atrorubens*, *Geum* sp, *Vicia* sp, *Hypericum* sp and *Stellaria media*. Some of these taxa were present in the open field portion of the transect (plots 1 to 3) as seedlings and rosette stages at the time of sampling and were often concealed by middle-height species such as *Solidago* sp (eg., *Daucus carota*, *Vicia* sp, *Hypericum* sp, and *Hieracium* sp).

The least variability in cover most often occured when taxa were seen during every visit to their transects. In these cases where % observance equalled 100%, %CV values ranged from 0 (eg., *Cirsium* sp, *Rumex crispus*) to 42.6% (*Arisaema atrorubens*) (Table 5).

Generally, plants growing at "middle" and "tall" heights had the lowest %CV values (< 30%) for cover estimations. Some examples include shrubs, Impatiens capensis, Polygonum persicaria, Solidago sp, Ranunculus sp, and trees.

The % observance values listed in Table 5 ranged from 7% to 100%. Of the 62 values of % observance obtained, 28 values (45%) were less than 100%. Of these 28 values, 23 (82%) corresponded to taxa whose cover estimations were less than 10%. Again, these taxa were often present as seedlings (eg., Daucus carota and Taraxacum officinale) or were low growing (eg., Stellaria media and Hieracium sp) and were found beneath the cover of middle-growing species (eg., Solidago sp and shrubs).

The %CV of total numbers of plant taxa in sampling plots are shown in Table 6 (pg 42). The %CV of data collected by this method ranged from 0 to 26.8% and were generally smaller than those observed in the estimation of cover (see comments regarding Table 5 above). Sampling conducted in the open field plots (plots 1 to 3) had higher %CV than those sampled beneath the forest canopy (plots 4 to 8) (Table 6).

Table 5: The % Coefficients of Variance (%CV) for cover** and % Observance*** of the plant taxa in eight 0.6m^2 plots set out along a 40m transect between an open field and forest in southern Ontario (N = 12 to 14 per plot).

TAXA	% CV	% OBSERVANCE
1) HERBACEOUS VEGETATION		
Cirsium sp	0	100
Rumex crispus	0	100
Ranunculus sp	5.0	100
	11.8	100
	15.0	100
	20.4	100
Solidago sp	5.8	100
	7.0	100
	7.5	100
	244.1*	15
Polygonum persicaria	8.1	100
	30.0	92
Impatiens capensis	8.5*	100
	9.7	100
	12.8	100
	36.1	92
Achillea millefolium	9.3	100
Fragaria virginiana	11.0	100
	15.6	100
	71.3	69
	122.4*	46
Dentaria sp	16.2	100
Prunella vulgaris	17.1	100
	21.7	100
	92.6*	57
Daucus carota	18.6	100
	83.2*	71
	198.7*	21
Arisaema atrorubens	42.6*	100
	346.4*	8
Senecio sp	44.4*	85
Taraxacum officinale	48.4*	85
	164.1*	29
	182.6*	29
Geum sp	54.2	79
	360.6*	8

Table 5 continued .....

Vicia sp	60.7	77
	117.2*	50
	374.2*	7
Trifolium pratense	77.3*	64
Hypericum sp	89.9*	57
	119.8*	43
	360.6*	8
Potentilla recta	112.6*	50
Stellaria media	119.8*	43
	156.8*	69
	360.6*	8
Hieracium sp	158.3*	31
	211.4*	21
2) SHRUBS		
Parthenocissus quinquefolia	0	100
Cornus sp	0	100
	8.2	100
	11.4	100
	11.8	100
Spiraea sp	8.9	100
Rubus sp	11.6	100
3) TREES		
Fraxinus sp	0	100
Acer sp	0	100
	3.6	100
	16.9	100
Ulmus sp	27.6	100
Carya sp	39.4	100

Note:

* indicates taxa whose coverage estimations were 10% and less.

** %CV of cover demonstrates repeatability of recording plant cover

*** % Observance (= number of times a taxon was seen/ total number of sampling repetitions of its plot (N= 12 to 14)) demonstrates repeatability of recording taxon presence

Table 6 : Total numbers of plant taxa observed per plot in the eight 0.6m^2 plots (sampled 12-14 times) of a 40m transect set out between an open field and a forest in southern Ontario. The % coefficients of variance of the total numbers are also listed.

Sampling Plots-	Sampling times and %Coefficients of Variance-														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	% CV
1/	10	8	9	12	9	11	10	10	9	10	10	10	9	-	10.4
2/	7	8	8	9	8	10	9	10	8	8	10	6	7	7	15.2
3/	6	5	6	4	8	6	10	9	7	4	7	9	8	8	26.8
4/	7	7	5	4	5	6	5	5	7	5	5	5	5	-	17.7
5/	4	4	4	4	4	5	4	4	4	4	4	4	-	-	7.1
6/	5	5	5	5	5	5	5	5	5	5	5	5	5	-	0.0
7/	3	3	3	3	3	3	3	3	3	3	3	3	3	-	0.0
8/	6	6	6	6	6	6	6	6	5	6	6	6	6	-	4.7

Note:

Sampling plots 1 to 3 were situated in open field (ie., no tree cover); sampling plots 4 to 8 were under forest canopy.

Unlike the methods of the main study, the sampling plots were not disturbed during sampling in this auxiliary study. Under the conditions of the auxiliary study, middle-growing taxa obscured from view many of the small, low-growing taxa within the plots. This was especially apparent in the open field where middle-growth species such as Cornus sp and Solidago sp were abundant. In the forest, however, there were no middle-growth species, only trees and small herbs.

Undoubtedly, disturbing the plots for better viewing of the plots would have improved the consistency in both recording taxon presence (ie., increased the % Observance values in Table 5) and total numbers of taxa in plots (ie., decreased the %CV listed in Table 6). It is less certain that disturbing the plots would have reduced the variance observed in the cover estimations (ie., decreased the %CV listed in Table 5). And, although cover estimations of plants is a method often used by plant ecologists, some concern regarding its accuracy and repeatability have been raised by some authors (eg., Sykes,et al.1983; Floyd and Anderson,1987; Kennedy and Addison,1987). The use of cover as a quantitative measure of vegetation abundance has been shown to be suitable for certain types of vegetation (eg., dominant shrub species, Floyd and Anderson,1987; and abundant species, Kennedy and Addison,1987). However, potential variability in cover (by both single investigators and between individuals in groups of investigators, see Sykes, et al.1983) suggests that they be used with caution in ecology. The results of this auxiliary study further demonstrate that cover data have the potential for large variability (for eg., from Table 5 the %CV for Vicia sp was 374.2%). Based on the above evidence and the findings of this auxiliary study, the measures of "success" that included cover (on its own or in calculations, eg., "volume") were excluded from further analysis in the main study due to the potential of large variability. However, data collected by recording presence of species and total numbers of species in plots were more repeatable and less variable than those collected by estimating cover.

Therefore, at this point in the interpretation of the results of the auxiliary study, the measures of "success" of introduced vegetation that were considered for subsequent analyses in the main study were:

i) Presence of introduced taxa in sampling plots,

ii) Total number of introduced taxa in sampling plots, and

iii) % Total number of introduced taxa in sampling plots.

B) Seasonal Variance

Table 3 demonstrates that Transects 9 and 9' show no apparent differences in the distributions of greater "success" of their introduced taxa when "success" is analyzed with the runs test as total numbers of introduced taxa of vegetation > transect median, % total number of introduced taxa of vegetation > transect median, and presence of introduced isopods and earthworms in plots.

The distributions of presence of introduced taxa of vegetation in plots and those vegetation measures using cover in their calculations were apparently affected by the season of sampling of their transects.

Subsequent Analyses in the Main Study

Because they demonstrated both less variability than cover estimations of vegetation in Part A) of the auxiliary study and no seasonal variability in Part B) of the auxiliary study, the measures of "success" that were concluded to be the most reliable of those designed in the main study were:

1) total numbers of introduced taxa of vegetation in sampling plots,
2) presence of introduced taxa of isopods in sampling plots, and
3) presence of earthworms in sampling plots.

The distributions of these measures of "success" (as analyzed by the runs test) were used in subsequent analyses in the main study and are listed in Tables 7 and 8 (pgs 46 and 47, respectively).

Table 7: Distributions of the "success" measures: total numbers of introduced taxa of vegetation > transect median and presence of introduced isopods and earthworms in Ø.6m^2 sampling plots along transects in SHORT HILLS PROVINCIAL PARK (excerpt from Table 3).

N = non-aggregated distribution (runs test P$\geq$.Ø5),
A = aggregated distribution (runs test P<.Ø5).

	Transect									
	1	2	3	4	5	6	7	8	9	9'
Vegetation	A	N	A	A	A	A	A	A	A	A
Isopods	N	N	N	N	N	N	N	N	A	A
Earthworms	A	A	A	A	N	N	A	N	N	N

Note:
Sampling dates of transects are listed in Table 1 (pg 19).

Table 8: Distributions of the "success" measures: total numbers of introduced taxa of vegetation > transect median and presence of introduced isopods and earthworms in $0.6m^2$ sampling plots along transects in BACKUS WOODS (excerpt from Table 4)

N = non-aggregated distribution (runs test $P \geq .05$),
A = aggregated distribution (runs test $P < .05$).

	Transect							
	1	2	3	4	5	6	7	8
Vegetation	A	A	A	-	A	A	A	A
Isopods	A	X	N	N	N	N	N	X
Earthworms	A	A	N	N	N	A	A	N

Note:

- indicates transects in which unidentifiable specimens yielded conflicting runs test results (see text pg 29).

X indicates transects in which <11 plots contained isopods (see text pg 30)

Sampling dates of transects are listed in Table 2 (pg 19).

3) <u>Proportions of Transects with Aggregated Distributions of Introduced Taxon "Success"</u>

Table 9 (pg 49) lists the proportions of aggregated and non-aggregated transects at both study sites (runs tests $P<.05$ and $P\geq.05$, respectively) of the most reliable measures of "success" of the introduced taxa studied (ie., calculated from the data in Tables 7 and 8).

Tests of significance (z statistic, two-sided test for comparison of proportions from independent samples) were conducted on the resulting proportions using a Zenith PC and the Tadpole III statistical package (Caradoc-Davies,1987). These tests indicated that the proportions of aggregated transects at Short Hills and Backus Woods in Table 9 were significantly greater than the expected 5% (53.33%, $z=4.12$, $P<.01$ and 57.14%, $z=3.65$, $P<.01$, respectively)

However, the proportion of aggregated transects obtained at Backus Woods was not significantly different from that obtained from Short Hills (from Table 9, $z=0.27$, $P>.05$).

Table 9: Proportions of transects with aggregated and non-aggregated distributions of the "success" measures: total numbers of introduced taxa of vegetation > transect median and presence of introduced isopods and earthworms in sampling plots for SHORT HILLS and BACKUS WOODS.

	1) SHORT HILLS (N = 30)	2) BACKUS WOODS (N = 21)
Aggregated	53.33%a	57.14%b
Non-aggregated	46.67%	42.86%

Note:

Z Statistics;

a vs 5%) z= 4.12, P<.01
b vs 5%) z= 3.65, P<.01
a vs b) z= 0.27, P>.05

4) Distributions of the "Success" of Introduced Taxa, presented by Group

The proportions of aggregated transects of introduced vegetation "success" at both sites were significantly greater than the expected 5% (90.00%, z=3.80, P<.01 and 100.00%, z=3.60, P<.01 for Short Hills and Backus Woods, respectively) (Table 10; pg 51). Similarly, the proportions of aggregated transects for earthworms were significant at both study sites (50.00%, z=2.30, P<.05 and 50.00%, z=2.00, P<.05 for Short Hills and Backus Woods, respectively) (Table 10).

The proportions of aggregated transects of introduced isopods were not, however, significantly greater than what would be expected at 5% at both study sites (20.00%, z=1.00, P>.05 and 16.67%, z=0.70, P>.05 for Short Hills and Backus Woods, respectively) (Table 10).

The proportions of aggregated transects for the introduced taxa of each of the groups were not significantly different between Short Hills and Backus Woods (see z statistics listed in Table 10).

Table 10: Proportions of aggregated transects (N given in parentheses) of "success" of introduced taxa, presented by group. Data for SHORT HILLS PROVINCIAL PARK and BACKUS WOODS.

	1) SHORT HILLS	2) BACKUS WOODS
Vegetation *	90.00% (10)a	100.00% (7)b
Isopods @	20.00% (10)c	16.67% (6)d
Earthworms #	50.00% (10)e	50.00% (8)f

Note:

"Success" was defined and analyzed with the runs test as, total number of introduced taxa of vegetation > transect median in sampling plots (*), presence of introduced isopods in sampling plots (@) and, presence of earthworms in sampling plots (#).

Z Statistics;

a vs 5%) z= 3.80, P<.01
b vs 5%) z= 3.60, P<.01
c vs 5%) z= 1.00, P>.05
d vs 5%) z= 0.70, P>.05
e vs 5%) z= 2.30, P<.05
f vs 5%) z= 2.00, P<.05
a vs c) z= 3.15, P<.01
a vs e) z= 1.95, P>.05
c vs e) z= 1.51, P>.05
b vs d) z= 2.18, P<.05
b vs f) z= 3.08, P<.01
d vs f) z= 2.18, P<.05
a vs b) z= 0.86, P>.05
c vs d) z= 0.17, P>.05
e vs f) z= 0.00, P>.05

5) Distribution Patterns of Introduced Isopods

Tables 11 and 12 (pgs 53 and 54) list the distributions of introduced isopods in sampling plots analyzed by Methods i) and ii) for the transects completed in Short Hills and Backus Woods, respectively.

There were no significant differences between the proportions of transects with aggregated distributions obtained by Methods i) and ii) at either site (Tables 11 and 12). In addition, neither method generated significant proportions of transects with aggregated distributions of introduced isopods at either site (see z statistics listed in Tables 11 and 12).

Table 11: Distributions of presence of introduced isopods in sampling plots along the transects sampled in SHORT HILLS PROVINCIAL PARK using Methods i) and ii)*.
A= aggregated distribution (runs test, $P<.05$)
N= non-aggregated distribution (runs test, $P\geq.05$)

Transect	Method i)	Method ii)
1	N (32)	A
2	N (21)	A
3	N (18)	N
4	N (35)	N
5	N (19)	N
6	N (11)	N
7	N (12)	A
8	N (23)	N
9	A (48)	N
9'	A (38)	A
	%A= 20.00a	%A= 40.00b

Note:

* In Method i), only sampling plots with individuals were analyzed with the runs test (plots per transect in parentheses); in Method ii), all sampling plots were analyzed with the runs test (60 plots per transect)

Z Statistics
a vs b) z= 0.98, P>.05
a vs 5%) z= 1.01, P>.05
b vs 5%) z= 1.87, P>.05

Table 12: Distributions of presence of introduced isopods in sampling plots along the transects sampled in BACKUS WOODS using Methods i) and ii)*.
A= aggregated distribution (runs test, $P<.05$)
N= non-aggregated distribution (runs test, $P\geq.05$)

Transect	Method i)	Method ii)
1	A (20)	A
2	X (0)	X
3	N (38)	N
4	X (3)	A
5	N (37)	N
6	N (33)	A
7	N (14)	N
8	N (11)	N
	%A= 16.67a	%A= 42.86b

Note:

* In Method i), only sampling plots with individuals were analyzed with the runs test (plots per transect in parentheses); in Method ii), all sampling plots were analyzed with the runs test (60 plots per transect).

X indicates transects in which <11 plots contained isopods (see text pg 30).

Z Statistics
a vs b) z= 1.15, P>.05
a vs 5%) z= 0.65, P>.05
b vs 5%) z= 1.01, P>.05

DISCUSSION

"Success" of Introduced Taxa

As was discussed previously (pgs 38-45) based on the results of both Parts A) and B) of the auxiliary experiment (Tables 3,5,and 6), the most reliable measures of "success" for the introduced taxa of the three groups of organisms studied were: total numbers of introduced taxa of vegetation in sampling plots greater than the transect median, presence of introduced isopods in sampling plots, and presence of earthworms in sampling plots.

Runs Test Analyses of Introduced Isopods

Tables 11 and 12 list the distributions of introduced isopods in sampling plots when, in Method i), only sampling plots with individuals (N=11 to 48) along the transects were analyzed with the runs test and, Method ii), when all sampling plots of transects (N=60) were analyzed with the runs test (ie., the analysis method used for vegetation and earthworms). Method i) was designed to eliminate uninhabitable sampling plots from analyses that would potentially be detected as gaps in the distributions of introduced isopods, whereas Method ii) included these uninhabitable sampling plots.

In Short Hills the proportions of aggregated transects of introduced isopods using Methods i) and ii) were

20.00 and 40.00%, respectively (Table 11). These proportions were not significantly different ($z=0.98$, $P>.05$) and neither was significantly greater than the 5% expected from a normal distribution (20.00%, $z=1.01$, $P>.05$ and 40.00%, $z=1.87$, $P>.05$).

In Backus Woods the proportions of aggregated transects of introduced isopods using Methods i) and ii) were 16.67 and 42.86%, respectively (Table 12). These proportions were also not significantly different ($z=1.15$, $P>.05$) nor were they significantly greater than the 5% expected (16.67%, $z=0.65$, $P>.05$ and 42.86%, $z=1.661$, $P>.05$).

Since no significant differences were found between the results generated by both methods at both study sites, and neither method generated significant aggregation of introduced isopods, either method was concluded to be suitable for runs test analysis of the distributions of introduced isopods. The results for isopods used for both presentation in Tables 3 and 4 and final analyses were those derived by Method i).

Aggregation of Introduced Taxon "Success"

The proportions of aggregated transects of introduced taxon "success" at both study sites were also compared to the 5% expected (Table 9). At both Short Hills and Backus Woods, these proportions were significantly greater than the 5% expected (53.33%, $z=4.12$, $P<.01$ and 57.14%, $z=3.65$, $P<.01$, respectively). Therefore, since aggregation was significant at the sites, these findings support the hypothesis that the "success" of introduced taxa is aggregated spatially in ecosystems containing gradients of anthropogenic disturbance severity (conversely, if the null hypothesis had been supported, the proportions of aggregated transects of introduced taxon "success" would have been equal to or less than the 5% expected, ie., $z<1.96$, $P>.05$). Given that the proportions of aggregated transects were significant and the transects encompassed gradients of anthropogenic disturbance severity, the data from this study were also consistent with the ecological principle that introduced taxa are more "successful" in the portions of ecosystems more disturbed by human activity than in the less disturbed portions of those ecosystems.

The proportions of aggregated transects of introduced vegetation "success" (90.00% and 100.00%) and earthworms (50.00% and 50.00%) at both Short Hills and Backus Woods (respectively) were significant (Table 10). Therefore, when assessed individually, introduced vegetation and earthworms both supported the hypothesis of this study and, at this point in the analysis of results, they were consistent with the principle tested.

However, the proportions of aggregated transects of introduced isopods (20.00% and 16.67% for Short Hills and Backus Woods) were not significant at both study sites (Table 10). Therefore, introduced isopods supported the null hypothesis of this study and, in turn, were not consistent with the principle of differential "success" of introduced taxa in disturbed and undisturbed portions of ecosystems.

In summary, therefore, the taxon assemblage, introduced taxa (ie., of all three groups of organisms combined), did support the hypothesis, whereas introduced isopods did not support the hypothesis when assessed alone. These results suggest that the "success" of the introduced taxa of some groups of organisms (eg., terrestrial isopods) may be less sensitive to the severity of human-induced disturbance than others (eg., vegetation and earthworms). Other studies have shown that some species have become successful invaders of relatively undisturbed ecosystems. Examples include the malaria mosquito (Anopheles gambiae), chestnut blight (Entothia parasitica), muskrat (Ondatra zibethica), starling (Sturnus vulgaris), cord-grass (Spartina anglica), the sea lamprey (Petromyzon marinus) and the chinese mitten crab (Eriocheir sinensis) (Holdgate,1986). Even nature reserves have experienced introduced taxon invasions. Usher (1988) discusses the generalizations arising from 24 case studies of nature reserves from which 1874 vascular plants and 177 vertebrates are documented as invasive species. It would appear, based on the above examples and the findings of this study, that the principle of differential "success" of introduced taxa in disturbed and undisturbed portions of ecosystems is not an all-encompassing generalization. These findings are becoming increasingly important as concern mounts regarding the effects of introduced species invasions into nature reserves (see Duffey,1988). In fact, Simberloff (1989) argues that undisturbed habitats may only appear to be less invasible than disturbed habitats in ecological literature for two reasons. First, since most disturbed habitats studied have been disturbed by humans- particularly agricultural habitats and dwellings- successful introductions into disturbed habitats have been studied "more carefully than pristine habitats" because both the disturbed habitats and the successful introductions are important to us. Consequently, successful introductions into undisturbed habitats may have been and are overlooked, unless the results of such introductions have been dramatic (eg., gypsy moth, chestnut blight, etc.). Second, opportunity for introduction into disturbed habitats has been "almost certainly greater" than introduction into undisturbed habitats. Imported animals and agricultural and ornamental plants must have been accompanied by their associated organisms (especially prior to the establishment of quarantine regulations). Many of these organisms, in turn, have become successful invaders (eg., "weed" seed contaminants of grains, see Mack (1989)). On the other hand, organisms from undisturbed ecosystems (ie., those not directly associated with agricultural commodities) would have been less likely to be introduced via human activities.

The observation that neither all of the groups sampled nor all transects yielded consistent runs test results of aggregation (or non-aggregation) (Table 3) led to the testing of the potential effects of disturbance severity gradients of the transects on the distributions of introduced taxon "success". For this reason the second field season was spent at a site containing steeper gradients of human-induced disturbance severity than Short Hills, Backus Woods. It was suspected that aggregation of introduced taxa would be more intense in Backus Woods than Short Hills because of the steeper gradients of anthropogenic disturbance severity along the transects of Backus Woods. It was suspected that more intense aggregation of introduced taxon "success" would generate a stronger biological signal for detection by the methods used. It still followed, however, that if no aggregation was occuring along the transects at Backus Woods, then a stronger gradient of disturbance severity would have no effect and non-aggregated distributions would still be noted. The hypothesis of this subsidiary test was that the proportions of aggregated transects at the two study sites would be significantly different; the null hypothesis was that these proportions would not be significantly different.

The proportion of aggregated transects of all three groups combined in Backus Woods (57.14%) was not significantly different from that obtained from Short Hills (53.33%) ($z=0.27$, $P>.05$) (Table 9). These data, therefore supported the null hypothesis of this subsidiary test.

Similarly, the proportions of aggregated transects assessed by group (Table 10) indicate that there were no significant differences between the results obtained for each group for each site (ie., vegetation vs. vegetation, etc.). These data also support the null hypothesis of this subsidiary test.

Therefore, the data suggest aggregation of introduced taxa may not actually intensify with increasing steepness of gradients of anthropogenic disturbance severity, as was first suspected in this test. Rather, the presence of a gradient of some minimal steepness may be enough to induce aggregation of introduced taxon "success" if the taxa is responsive to human-induced ecosystem disturbance (recalling again that introduced vegetation and earthworms appeared to be responsive in this sense, whereas isopods were not at both study sites).

There is also the possibility that the differences between the disturbance gradients at the two sites were so slight that they did not induce sufficiently different aggregation intensities that could be detected by the methods used. The methods used were sensitive to some degree of difference in aggregation intensities of the introduced taxa in this study. This is based on both the observations that runs test probability values varied amongst transects and the proportions of aggregated transects were significantly different between certain combinations of groups at both Short Hills and Backus Woods (Table 10). That is, all three groups in

Backus Woods were significantly different from each other in this respect and in Short Hills there were significantly more aggregated transects of the "success" of introduced vegetation than for isopods. However, at this point, both the minimal steepness of disturbance gradients and the degree of difference in aggregation intensity that would have generated a significant difference between Short Hills and Backus Woods is unknown.

Suggestions for Further Study

Although the introduced taxa (as a unit) supported the hypothesis of this study and were consistent with the principle tested, these results have by no means proven the principle that introduced taxa are more "successful" in the portions of ecosystems more disturbed by human activity than in the less disturbed portions of those ecosystems. One additional task would be to test whether greater introduced taxon "success" was located in the portions of ecosystems more disturbed by human activity than in the less disturbed portions of ecosystems. Identification of such a relationship would further support the principle of differential "success" of introduced taxa in disturbed and undisturbed portions of ecosystems.

Attempts were made in this study to assess visually aggregation patterns along the transects that yielded runs test probabilities of $P<.05$ in both Short Hills and Backus Woods. Although admittedly superficial, these visual assessments did indicate consistent aggregation of introduced vegetation towards the more disturbed portions of their transects which supported both the hypothesis of this study and were consistent with the principle tested. Earthworms, on the other hand, tended to aggregate towards the less disturbed portions of their transects which was not consistent with the principle that introduced taxa are more "successful" in the portions of ecosystems more disturbed by human activity than in the less disturbed portions of those ecosystems. This pattern was especially evident in Short Hills where all 5 transects with runs test results of $P<.05$ for earthworm presence (shown in Tables 3 and 7) demonstrated earthworm aggregation towards their forested portions. Of the 4 transects with runs test results of $P<.05$ for earthworm presence in Backus Woods (shown in Tables 4 and 8), one demonstrated aggregation of earthworms towards its forested portion (the remaining 3 were not aggregated towards either open field or forest).

The visual assessments refered to above generated two important points of discussion. First, although the extremes of disturbance severity could be recognized, there were no definitive, identifiable boundaries between the more disturbed and less disturbed portions of the transects sampled in Short Hills and Backus Woods. For this reason, it became apparent that there would be no obvious identifiable boundaries to use as guideines for relating the locations of greater introduced taxon "success" and greater ecosystem disturbance severity. The following are suggested methodologies for future study that would overcome this obstacle and will further test the principle of differential "success" of introduced taxa in disturbed and undisturbed portions of ecosystems.

Harmon,et al.(1983) devised parameters to describe quantitatively the characteristics of a given disturbance. These parameters vary along disturbance gradients in ecosystems and include severity, intensity, frequency, predictability, area, and cycle of disturbance. If one knew the values of these parameters along the length of a transect and knew the degree of "success" of introduced taxa along the same transect, then one could test for a correlation between the location of greater introduced taxon "success" and greater values of disturbance characteristics. Unfortunately, the abundant, detailed, historical information required to test for such a correlation by this method is inhibiting (particularly for undisturbed and relatively undisturbed portions of ecosystems) (Rogers,1978; Lorimer,1980) and would only be feasible in cases where the data were available. Such detailed data were unavailable for Short Hills and Backus Woods.

An alternative approach would be to manipulate experimentally the disturbance characteristics of an ecosystem (eg., severity, intensity, duration, etc). Some of the many recent studies that have used experimentally manipulated disturbance to examine ecosystem properties include Reader (1987), Conn and Delapp (1983), and Gibson (1988). The following suggested protocol is a modification of that used by Conn and Delapp (1983). It requires cultivation (an example of a severe disturbance) of a consecutive series of fields for a known number of years. The greater the age of a field (ie., the more years it is in cultivation) the more disturbed that field is at the time of sampling. A transect could be placed so as to encompass each field thereby encompassing a range of some disturbance character (eg., duration of disturbance, that is, field age). Sampling plots would be placed along this transect so as to assess introduced taxon "success" (as it has been defined in this study) in each field.

Data from this transect can generate three parallel vectors of binary conditions: one of values of introduced taxon "success" > vs ≤ the transect median; a second of field age > vs ≤ the transect median; and a third vector of sampling points in which both introduced taxon "success" and field age are > their transect medians vs any other combination of these two values. This approach is illustrated in Figure 1 (pg 67).

Aggregation of sampling points in which both introduced taxon "success" and field age are > their transect medians along this third vector support the hypothesis that introduced taxa are more "successful" in the portions of ecosystems more disturbed by human activity than in the less disturbed portions of those ecosystems. The runs test could again be used to distinguish between aggregated and non-aggregated patterns of the above condition.

Figure 1: Runs test analysis of the comparison of three hypothetical parallel transects (see text pgs 65-66).

	Results per sampling plot
* Field Age	- - - - - - - - - - + + + + + + + + + +
* Introduced Taxon "Success"	+ + + - + - - - - - + + + + + + - - + -
"Vector 3"	- - - - - - - - - - + + + + + + - - + -

Runs Test analysis of "Vector 3":

runs = 5
$P = 9.55 \times 10^{-3}$

Since P<.05, therefore, the pattern evident along Vector 3 is aggregated.

Note:

* transects whose binary conditions are above (+) vs. at/below (-) their transect medians

"Vector 3" consists of sampling plots in which both field age and introduced taxon "success" are > their transect medians (+) vs. any other combination of these two values (-).

Obviously, experimental manipulation of the disturbance characteristics of an ecosystem is not always possible, as was the case in Short Hills and Backus Woods. An alternative approach may be to utilize some intrinsic character of ecosystems that reflect their disturbance condition. For example, if less disturbed ecosystems tend to have older and, in turn, larger trees, then tree diameter may prove to be such a character. It would follow that finding smaller trees in areas where introduced taxon "success" is greater will support the principle of differential "success" of introduced taxa in disturbed and undisturbed portions of ecosystems.

The second point worthy of note from the visual assessments of the transects in this study was that earthworms tended to aggregate towards the less disturbed portions of their transects. As was discussed previously (pgs 16-17), all of the terrestrial earthworms encountered in this study are considered to be introduced species (Reynolds,1977). The "Post Quaternary Introduction Theory" suggests that the entire megadrile fauna of the once-glaciated portions of North America (which includes Canada and southern Ontario) was exterminated at the time of the last glaciation and earthworms have re-invaded these areas from Europe via intentional and accidental human intervention (Gates,1929;1954; 1966;1976;1978;1979;1982; Reynolds,1975a;1975b;1976;1977).

The peregrine (wandering) or allochthonous (originating outside of a given area) earthworms are considered to be very "adaptable" invaders of disturbed habitats (Hutchinson,1978; Sims and Gerard,1985). In South Africa, for example, where the endemic earthworm population is very diverse, invasion of introduced earthworms into undisturbed habitats is "extremely rare" (Hutchinson,1978). The aggregation of earthworms towards the less disturbed portions of the ecosystems sampled in this study contradicts the above findings. It may be, as suggested by Lee (1985), that during the post-glacial reinvasion of earthworms to the glaciated portions of North America (including the sites of this study) the earthworms did not have to contend with competition from any endemic species and were "free" to invade any suitable portions of the ecosystems available (disturbed and undisturbed). The data collected in this study are consistent with the explanation proposed by Lee (1985). However, there exists a need for additional hypotheses testing in the subject of both earthworm origins in North America (Ball,1975) and their response to anthropogenic disturbance. For instance, in light that there is controversy regarding the Post Quaternary Introduction Theory itself (Omodeo,1963; Ball,1975; Schwert,1979; McKay-Fender and Fender,1982) it is suggested that additional hypotheses pursue the significance of earthworm response to anthropogenic disturbance as it pertains to the conviction that most are introduced species in Canada. The data from this study suggest that earthworms are responding to anthropogenic disturbance by aggregating along anthropogenic disturbance gradients, but they are not "behaving" as is predicted for introduced taxa (ie., aggregating in the portions more disturbed by human activity).

Another worthwhile direction of study would be to test whether introduced taxa are differentially "successful" in ecosystems that have experienced gradients of natural (as opposed to anthropogenic) disturbance severity using the methods of this study. The hypothesis is that the "success" of introduced taxa is spatially aggregated along transects that encompass gradients of natural disturbance severity; the null hypothesis being that their "success" is not spatially aggregated along such transects. Types of natural disturbance that could be considered for focus in such a study would include lightning fires, forest canopy gaps (by windfall, ice storms, insect infestations, etc.) and erosion. Support for the above hypothesis may aid in understanding of introduced taxon invasions into ecosystems relatively undisturbed by human activity.

The Ecological Challenge of Introduced Taxa

Although they are not always undesirable (eg., the European orchid, *Epipactis helleborine* (L.)Crantz in Ontario; Soper and Gray,1954), generally invasions of introduced taxa are perceived as threats, especially to "pristine" areas, such as national parks (Machlis and Tichnell,1987). Introduced taxa have been shown to induce a variety of changes in ecosystems (see Kruger,1989; Mack,1989). Macdonald,et al.(1989) discuss several changes that they categorize as: acceleration of soil erosion rates (eg., grazing, browsing, and trampling of feral animals), alteration of geomorphological processes (eg., sand dune formation by the introduced plant, *Ammophila arenaria*), alteration of biogeochemical cycling (eg., the nitrogen-fixing plants, *Myria faya* and *Leucaena leucocephala*, on nitrogen-poor Hawaiian lava flows), alteration of fire regimes (in all cases cited, in North America and Australia change is in favour of increased fire frequency with introductions) and the prevention of recruitment of native species (eg., the inhibition of woodland regeneration in Ireland by the introduced shrub *Rhododendron ponticum*). Ashton and Mitchell (1989) discuss the dramatic effects of successful introductions into aquatic ecosystems (eg., the aquatic plant *Eichhornia crassipes*). In some cases, introduced taxa appear to be forcing endemic taxa into local or even global extinction. This direct association between native and introduced taxa is often difficult to prove however, when shown, it has been more pronounced on islands as compared to continents. Although several extinctions of island taxa have been attributed to introductions (other than humans), no such cases have been shown for continental taxa (although some species have come to the brink of extinction because of introduced taxa) (Macdonald,et al.1989).Some examples in which this effect appears to be materializing include the displacement of Taxodium ascendens (cypress) by Melaleuca quinquenervia (melaleuca) in southern Florida (Ewel,1986), the destruction of Abies fraseri (Douglas fir) by Adelges picea (balsam woolly aphid) in the Great Smoky Mountains (Harmon, et al.1983) and the loss of endemic bird species due to predation from introduced rats (Rattus species) on the Hawaiian Islands (Moulton and Pimm,1986). Additional examples, of which there are many, are discussed by Simberloff (1981) and Macdonald,et al.(1989).

Pimm (1987) suggested that "islands" of endemic biota (such as national parks and nature reserves) may be susceptible to the same devastating effects of introduced species invasions (eg., extinction of endemic species) that oceanic islands have experienced (see Elton,1958; Crosby,1986; Moulton and Pimm,1986; Macdonald,et al.1989). Duffey (1988) consolidated several studies of case histories of introduced taxon invasions into nature reserves. Fortunately, at least at this point in time, these invasions do not appear to be supporting the ominous prediction made by Pimm (1987).

Macdonald,et al.(1989) suggest this occurence is unlikely since "this vulnerability (of oceanic islands) stems from a history of evolution in isolation, something which to a large extent cannot manifest itself in continental situations". Nonetheless, campaigns to eliminate introduced taxa from various ecosystems are widespread (eg., Holmes,et al.1987; Dahlsten,1986; Ashton and Mitchell,1989). The choice to execute an eradication program for an invasive organism requires careful economic and environmental cost/benefit analyses (Dahlsten,1986). Such programs have had variable success. Ashton and Mitchell (1989) discuss some of the attributes of successful programs in aquatic ecosystems, many of which are undoubtedly applicable to terrestrial ecosystems (eg., the importance of follow-up programs, accessibility of terrain, careful consideration of potential side-effects of programs, etc.)

Scientific focus towards understanding the dynamics and effects of invasions of introduced taxa has been intensified very recently. A recent SCOPE (Scientific Committee on Problems of the Environment) program (1982 to 1986) geared to this focus is evidence of this situation (see Groves and Burdon,1986; Mooney and Drake,1986; Kornberg and Williamson,1987; Drake, et al.1989). Understanding the consequences of introduced taxon invasions is of utmost importance in the development and application of both "classical" biological control strategies (ie., the control of a pest species via introduction of its natural enemies; van den

Bosch,et al.1982), the release of agricultural and ornamental cultivars (Mack,1989), the release of genetically-engineered organisms (a type of introduced organism), and the preservation of diversity of native biota. At this time, however, the answers to many pertinent ecological and genetic questions regarding introduced taxa and their invasions have proven elusive. For instance, based on numerous reviews of many examples of successful invasions, several trends have been identified in the characteristics of both introduced taxa (Bazzaz,1986; Ehrlich,1986; Holdgate,1986) and sites (Orians,1986; Holdgate,1986) that typify ideal conditions for successful invasions. Such invasions depend upon the often complex inter-relationship between the attributes of an introduced organism and its new environment (Noble,1989). Some attributes of a successful invader include: abundance in its original range, polyphagous, short generation times, much genetic variability, fertilized female able to colonize alone, larger than most relatives, association with Homo sapiens, and ability to function in a wide range of physical conditions (taken from Table 5.1 of Ehrlich,1986). Attributes of invasible habitats include: simplified communities (by disturbance or otherwise, such as the natural habitats of small islands) (Orians,1986) and climatic similarities between the origins and the new habitats of introduced taxa (Holdgate,1986).

Despite the identification of such trends, because of the many exceptions to the rules it is still not possible to accurately predict whether a favoured organism will actually become a successful invader (Moyle,1986; Ehrlich,1986; Williamson,1988; Ashton and Mitchell,1989; Mack,1989). Nor is it decisively known why some species of introduced taxa can invade relatively undisturbed communities (Orians,1986). Without answers to questions such as those above, the intentional release of introduced taxa should be approached with much caution (Regal,1986; Williamson,1988; Levin,1988; Simonsen and Levin,1988; Ellstrand,1988). Past experience of invasions has shown that even though the probability of an invasion succeeding is small, the risk from a successful invasion is large (Williamson,1988).

This study has added to the understanding of introduced taxon invasions by supplying further supportive evidence to the ecological principle maintained by Elton (1958) and others in ecology that introduced taxa are more "successful" in the portions of ecosystems more disturbed by human activity than in the less disturbed portions of those ecosystems. The principle was supported by the introduced taxa (as a unit of all three groups of organisms studied) and introduced vegetation (when it was assessed individually). The notable exceptions observed from the results include introduced isopods, which were not consistent with the principle when assessed individually and, although earthworms were responding to the anthropogenic disturbance in the ecosystems studied, they did not appear to be responding as predicted for introduced taxa.

If the principle of differential "success" of introduced taxa in disturbed and undisturbed portions of ecosystems was to withstand the rigours of further scientific study (some examples of which were described on pgs 62-68) and anthropogenic disturbance continues to expand, it appears conservation biologists will be faced with the challenge of dealing with the potential of world biota homogenization. Elton (1958) predicted: "If we look far enough ahead, the eventual state of the biological world will become not more complex, but simpler- and poorer. Instead of six continental realms of life, with all their minor components of mountain tops, islands, and fresh waters, separated by barriers to dispersal, there will be only one world, with the remaining wild species dispersed up to the limits set by their genetic characteristics, not to the narrower limits set by mechanical barriers as well."

CONCLUSIONS

In this study the spatial distributions (aggregated vs. non-aggregated) of the "success" of introduced taxa of terrestrial vegetation, isopods, and earthworms (as a unit and by group) were determined with the runs test in two southern Ontario ecosystems, Short Hills Provincial Park and Backus Woods/Backus Woods Conservation Area. The hypothesis tested was that greater "success" of the introduced taxa of these groups would be spatially aggregated along transects set out in these ecosystems that encompassed gradients of anthropogenic disturbance severity; the null hypothesis was that greater "success" of the introduced taxa would not be aggregated along these transects. Each of the 18 transects sampled traversed both portions of open fields (ie., the more disturbed extremes of the ecosystems) and forest (ie., the less disturbed extremes of the ecosystems). Support of the above hypothesis is consistent with the ecological principle that introduced taxa are more "successful" in the portions of ecosystems more disturbed by human activity than in the less disturbed portions of those ecosystems.

"Success" was initially defined by several measures designed to reflect the presence, level of abundance, and amount of physical space occupied by the introduced taxa in the ecosystems. An auxiliary study (consisting of two distinct experiments) was conducted to determine the most reliable measures of introduced taxon "success" designed in the main study. One experiment of this auxiliary study was an assessment of the repeatability of the methods used to collect vegetation field data. The other experiment was an examination of potential seasonal variability in the methods used for all three groups. The measures concluded to be the most reliable of those initially proposed were:

i) total numbers of introduced taxa of vegetation in sampling plots,

ii) presence of introduced isopods in sampling plots, and

iii) presence of earthworms in sampling plots.

Runs test analyses were conducted on all of the candidate measures of "success", however final analyses and conclusions were based on the results obtained for the above most reliable measures. These conclusions were as follows:

1) When treated as a unit, the introduced taxa of all three groups were significantly aggregated in both study sites. This result both supported the hypothesis of this study and was consistent with the principle tested.

2) When assessed by group, introduced vegetation and earthworms were significantly aggregated within both study sites. Therefore, introduced vegetation and earthworms supported the hypothesis.

3) Introduced isopods were not significantly aggregated within

both study sites. Therefore, introduced isopods supported the null hypothesis.

Preliminary visual assessments of the transects were attempted, and although no definitive conclusions based on these assessments can be stated, the following trends were apparent and will require further study:

4) Greater "success" of introduced vegetation tended to aggregate towards the more disturbed portions of the transects (ie., the open fields).
5) Earthworms, however, tended to aggregate towards the less disturbed portions of the transects (ie., the forests).

Further study is needed to test quantitatively whether the "success" of these introduced taxa was aggregated in the portions of the ecosystems apparent from these preliminary visual assessments of the transects. Suggested methodologies were discussed. At this time it was concluded that:

6) Introduced vegetation consistently support the hypothesis and the principle tested in this study.
7) Introduced isopods do not support the hypothesis and, hence, were not consistent with the principle tested.
8) Earthworms supported the hypothesis, but further study is

required to determine whether they do in fact support the principle tested.

Because no consistent results were obtained for all transects and all groups from Short Hills (ie., the first field season), the second field season was spent at Backus Woods where transects could traverse steeper anthropogenic disturbance severity gradients than Short Hills. It was suspected that these steeper gradients would intensify aggregation of introduced taxa and, in turn, the proportions of transects demonstrating aggregation of introduced taxon "success" would be significantly different between the two study sites. Comparison of the results obtained from both study sites revealed that:

9) There were no significant differences between the results obtained from both study sites.

The data suggest, therefore, that aggregation intensity of introduced taxon "success" is not actually influenced by the strength of disturbance gradients. It is also possible, however, that the differences between the disturbance gradients at the sites were not sufficiently large to induce significantly different aggregation.

In light of the results of this study and the present concern and research regarding introduced taxon invasions that are both intentional (eg., biological control and DNA-recombinant organisms) and unintentional (eg., invasions into nature reserves) the following points were made:

10) Many questions regarding introduced taxa and the consequences of their invasions are still unanswered.
11) Intentional releases of introduced taxa and genetically-engineered organisms should proceed with caution.
12) The ecological principle tested in this study, like many of the general trends observed in introduced taxon invasions, does not apply to all introduced taxa. Hence, although it may serve as a guideline in both understanding and testing hypotheses regarding introduced taxon invasions, it is not a predictive tool of the "success" of specific introduced taxa in their new ecosystems.

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Appendix 1: Conceptual Framework of the Methods Used

Two-Phase Mosaics

Ecological maps are often viewed as two-phase mosaics for study of pattern in landscapes. The phases of such mosaics can be defined in many ways, depending on the pattern being sought and the hypotheses being tested. For example, one may want to detect whether a plant species is aggregated in an ecosystem. Two useful phases to examine in this example would be a patch phase (where the plant is found) and a gap phase (where the plant is absent) (Pielou,1969). The boundaries between phases may or may not be distinct and recognizable, some phases gently merge into one another (Pielou,1976).

Two-phase mosaics are interpreted differently from the "dot maps" often used to analyze patterns of distinct individuals of plant species (Pielou,1969). For discussions of dot maps see Kershaw (1964) and Pielou (1969,1976). One fundamental difference between dot maps and two-phase mosaics is their standards of randomness. The Poisson distribution defines randomness for dot maps, whereas L-mosaics and S-mosaics typify randomness for two-phase mosaics (Pielou,1969). L-mosaics provide a "better standard of randomness than the S-mosaic" (Pielou,1969). For an account of the generation of L- and S-mosaics, see Pielou (1969; pgs 141-149).

Mosaics are generally sampled by point observations (eg., presence or absence of a species). This can create problems when a plant species, for example, forms very open aggregations (ie., low intensity aggregation). Spaces within patches may inadvertently be treated as gaps (Pielou,1969). To alleviate this problem, Pielou (1969) suggests that rather than sample true points in mosaics, it is often advantageous to sample small circular plots so that all of the plants that both cover and are in plots are considered in the determination of the point observation. Although plot size is arbitrary, it is important that it be smaller than the size of the patches being examined (Pielou,1969). In this way, plot size will be less likely to obscure patch and, in turn, phase pattern (ie., few plots will straddle both patches and gaps). This condition would then minimize plot size effects on the phase patterns. In addition, plots must be placed in both phases of a mosaic to detect pattern, if it is present.

This study

The objective of this study was to test for non-randomness in a two-phase mosaic of phases defined as: greater and lesser introduced taxon "success". As detailed in the methods, greater and lesser "success" were defined quantitatively. This study was not, however, an examination of dot maps of introduced taxon presence.

Superimposed upon the above mosaic were continua of anthropogenic disturbance severity. Theoretically, disturbance severity within the landscapes studied could also be perceived as mosaics (consisting of undisturbed and disturbed phases), but the detailed information (ie., disturbance history) required to define the phases of such a mosaic was not available. Recall, however, that although the phases of this latter mosaic could not be defined precisely (and quantitatively), the extremes of the phases (ie., the extremes of disturbance severity) were recognizable as open fields (more disturbed) and forests (less disturbed).

To test whether disturbance severity could be inducing pattern in mosaics of greater and lesser introduced taxon "success", transects that encompassed continua of severity were the logical choice of sampling technique (given that boundaries between the more disturbed and the less disturbed portions of the ecosystems were not recognizable). The length of transects (300m) was long enough to traverse the extremes of disturbance severity in the ecosystems (open fields and forests). In addition, it was anticipated that they were long enough to traverse both phases of greater and lesser introduced taxon "success" (the actual sizes of these phases, however, were unknown during sampling). Sample plots ($0.6m^2$) were placed randomly within 5m subsections of the transects to maximize numbers of point observations taken from both phases of each transect. It was felt that larger subsections would possibly skip over phases, but smaller subsections would be too detailed. Plot sampling was conducted rather than point sampling to minimize the problems associated with possible low intensity aggregation of introduced taxon "success".

Subsequently, the runs test was the test of choice for this study. It is suited to examination of pattern along linear maps of two-phase conditions, or, in other words, binary conditions (Pielou,1969;1976;1979). The example of a runs test analysis given in Pielou (1979) has been repeated here (pg 108) for illustration.

Example of a Runs Test Analysis (Pielou,1979: pg 283).

Let a sequence of presences (+) and absences (-) noted from 20 sampling plots along a transect be,

+ + + - + - - - - - - - - - - - + + - +

M = the number of presences = 7
N = the number of absences = 13
r = the number of runs (ie., uninterrupted sequences of symbols of either kind) = 7

The probability that there would be exactly r runs if M presences and N absences were randomly mingled equals,

i) when r is an even number (ie., r=2k since there would be k runs of presences and k runs of absences)

$$p(2k) = \frac{2\binom{M-1}{k-1}\binom{N-1}{k-1}}{\binom{M+N}{N}}$$

ii) when r is an odd number (ie., r=2k+1 since there would be k runs of presences and k+1 of absences, or vice versa)

$$p(2k+1) = \frac{\binom{M-1}{k-1}\binom{N-1}{k} + \binom{M-1}{k}\binom{N-1}{k-1}}{\binom{M+N}{N}}$$

The probability that there would be r or fewer runs (no less than 2) equals,

$$P(r) = \sum_{j=2}^{r} p(j)$$

If P(r) is small (less than 5%) then the null hypothesis (ie., no grouping of + and - relative to each other) can be rejected at the 5% significance level. Then it can be concluded that the presences and absences occur in unexpectedly long runs (ie., they were aggregated).

Therefore, in this study, $P<.05$ defines an aggregated distribution pattern. On the other hand, if $P\geq.05$, the pattern is concluded to be non-aggregated.

In the above example, $r= 7$, $P(r)= 0.095$, hence the pattern shown is non-aggregated.

Appendix 2: Species List for Short Hills Provincial Park

(Vegetation and Isopods)

Note: * indicates introduced taxa

# indicates taxa whose origins were unknown or uncertain

1) Vegetation (from Gleason and Cronquist, 1963)

Division Pteridophyta

Order Equisetales

Family Equisetaceae

Species *Equisetum arvense* L.

Order Filicales

Family Polypodiaceae

Species *Dryopteris marginalis* (L.) Gray.

Polystichum acrostichoides (Michx.) Schott.

Division Spermatophyta

Class Gymnospermae

Order Coniferae

Family Cupressaceae

Species *Juniperus virginiana* L.

Thuja occidentalis L.

Family Pinaceae

Species *Larix laricina* (DuRoi) K.Koch.

Picea pungens Engelm.

Pinus resinosa Ait.

Pinus strobus L.

Tsuga canadensis (L.) Carr.

Class Angiospermae

Subclass Monocotyledoneae

Family Araceae

Species _Arisaema triphyllum_ (L.) Schott.

Family Liliaceae

Species _Allium triococcum_ Ait.

* _Asparagus officinalis_ L.

Erythronium americanum Ker.

Smilacina racemosa (L.) Desf.

Subclass Dicotyledoneae

Family Aceraceae

Species _Acer negundo_ L.

Acer saccharinum L.

Acer saccharum Marsh.

Family Anacardiaceae

Species _Rhus radicans_ L.

Rhus typhina L.

Family Aristolochiaceae

Species _Asarum canadense_ L.

Family Asclepiadaceae

Species _Asclepias syriaca_ L.

Family Balsaminaceae

Species _Impatiens capensis_ Meerb.

Family Berberidaceae

Species _Podophylum peltatum_ L.

Caulophyllum thalictroides (L.) Michx.

Family Betulaceae

Species *Betula papyrifera* Marsh.

Carpinus caroliniana Walt.

Ostrya virginiana (Mill.) K. Koch

Family Caprifoliaceae

Species *Viburnum acerifolium* L.

Family Caryophyllaceae

Species * *Cerastium vulgatum* L.

* *Stellaria media* (L.) Cyrill.

Family Celastraceae

Species *Celastrus scandens* L.

Family Compositae

Species *Achillea millefolium* L.

Ambrosia artemisiifolia L.

* *Anthemis cotula* L.

* *Arctium minus* Schk.

Aster sp

Aster dumosus L.

Aster laevis L.

Aster patens Ait.

Bidens sp

Bidens frondosa L.

* *Chrysanthemum leucanthemum* L.

* *Cirsium arvense* (L.) Scop.

Cirsium discolor (Muhl.) Spreng.

* *Cirsium vulgare* (Savi) Tenore.

Erigeron annuus (L.) Pers.

Erigeron philadelphicus L.

Erigeron strigosus Muhl.

Eupatorium rugosum Houtt.

* *Hieracium pratense* Tausch.

Lactuca serriola L.

* *Onopordum acanthium* L.

* *Senecio vulgaris* L.

Solidago sp

Solidago canadensis L.

Solidago graminifolia (L.) Salisb.

Solidago nemoralis Ait.

Solidago uliginosa Nutt.

* *Sonchus arvensis* L.

* *Taraxacum officinale* Weber.

Family Convolvulaceae

Species * *Convolvulus arvensis* L.

Family Cornaceae

Species *Cornus* sp

Cornus alternifolia L.f.

Cornus stolonifera Michx.

Family Cruciferae

Species * *Alliaria officinalis* Andrz.

Arabis canadensis L.

* *Barbarea vulgaris* R.Br.

Dentaria lacinata Muhl.

* *Lepidium campestre* (L.) R.Br.

Family Dipsacaceae

Species * *Dipsacus sylvestris* Huds.

Family Euphorbiaceae

Species *Acalypha rhomboidea* Raf.

Family Fabaceae

Species *Lathyrus palustris* L.

* *Lathyrus tuberosus* L.

* *Medicago lupulina* L.

* *Melilotus alba* Desr.

Phaseolus polystachios (L.) BSP.

Robinia pseudoacacia L.

* *Trifolium pratense* L.

* *Vicia cracca* L.

Family Fagaceae

Species *Fagus grandifolia* Ehrh.

Quercus alba L.

Quercus rubra L.

Quercus velutina Lam.

Family Geraniaceae

Species *Geranium robertianum* L.

Family Hamamelidaceae

Species *Hamamelis virginiana* L.

Family Hypericaceae

Species * *Hypericum perforatum* L.

Family Juglandaceae

Species *Carya cordiformis* (Wang.) K.Koch.

Carya ovata (Mill.) K.Koch.

Juglans nigra L.

Family Labiatae

Species * *Glechoma hederacea* L.

Lycopus uniflorus Michx.

Monarda fistulosa L.

* *Prunella vulgaris* L.

Family Oleaceae

Species *Fraxinus americana* L.

Family Onagraceae

Species *Circaea quadrisulcata* (Maxim.) Franch.and Sav.

Epilobium angustifolium L.

Family Oxalidaceae

Species *Oxalis stricta* L.

Family Phrymaceae

Species *Phryma leptostachya* L.

Family Plantaginaceae

Species * *Plantago lanceolata* L.

* *Plantago major* L.

Family Polygonaceae

Species # *Polygonum aviculare* L.

* *Polygonum persicaria* L.

Polygonum virginianum L.

* *Rumex acetosella* L.

* Rumex crispus L.

Family Primulaceae

Species * Lysimachia nummularia L.

Oenothera biennis L.

Family Ranunculaceae

Species Actaea alba (L.) Mill.

* Ranunculus acris L.

Ranunculus recurvatus Poir.

Thalictrum polygamum Muhl.

Family Rhamnaceae

Species * Rhamnus catharticus L.

Rhamnus alnifolius L'Her.

Family Rosaceae

Species Agrimonia striata Michx.

Amelanchier laevis Wieg.

Aronia melanocarpa (Michx.) Ell.

Crataegus sp

Fragaria virginiana Duchesne.

Geum aleppicum Jacq.

Geum canadense Jacq.

Geum virginianum L.

* Potentilla recta L.

Potentilla simplex Michx.

* Prunus avium L.

Prunus serotina Ehrh.

Prunus virginiana L.

* <u>Pyrus</u> <u>malus</u> L.

* <u>Rosa multiflora</u> Thunb.

<u>Rubus</u> <u>allegheniensis</u> Porter.

<u>Rubus</u> <u>idaeus</u> (var.strigosus)(Michx.) Maxim.

<u>Rubus</u> <u>occidentalis</u> L.

Family Rubiaceae

Species <u>Galium</u> <u>aparine</u> L.

<u>Galium</u> <u>asprellum</u> Michx.

<u>Galium</u> <u>triflorum</u> Michx.

* <u>Galium</u> <u>mollugo</u> L.

Family Salicaceae

Species <u>Populus</u> <u>tremuloides</u> Michx.

<u>Salix</u> sp

* <u>Salix</u> <u>babylonica</u> L.

Family Saxifragaceae

Species <u>Ribes</u> <u>cynobati</u> L.

Family Scrophulariaceae

Species * <u>Verbascum</u> <u>thapsus</u> L.

* <u>Veronica</u> <u>officinalis</u> L.

<u>Veronica</u> <u>serpyllifolia</u> L.

Family Solanaceae

Species * <u>Solanum</u> <u>dulcamara</u> L.

Family Staphyleaceae

Species <u>Euonymus</u> <u>obovatus</u> Nutt.

Family Tiliaceae

Species <u>Tilia</u> <u>americana</u> L.

Family Ulmaceae

Species *Ulmus americana* L.

Ulmus rubra Muhl.

Family Umbelliferae

Species * *Daucus carota* L.

Family Urticaceae

Species * *Urtica dioica* L.

Family Verbenaceae

Species *Verbena stricta* Vent.

Family Violaceae

Species *Viola* sp

Viola incognita Brainerd.

Viola papilionacea Pursh.

Viola primulifolia L.

Family Vitaceae

Species *Parthenocissus vitacea* (Knerr) Hitchc.

Vitis riparia Michx.

2) *Isopods* (from Judd,1965; Barnes,1984)

Phylum Crustacea

Class Malacostraca

Order Isopoda

Sub-order Oniscoidea

Family Armadillidiidae

Species * *Armadillidium vulgare* (Latrielle)

Family Oniscidae

Species * _Cylisticus convexus_ (DeGeer)

* _Oniscus asellus_ L.

* _Tracheoniscus rathkei_ (Brandt)

Family Trichoniscidae

Species _Trichoniscus demivirgo_ Blake

Appendix 3: Species List for Backus Woods/Backus Woods Conservation Area (Vegetation and Isopods)

Note: * indicates introduced taxa

# indicates taxa whose origins were unknown or uncertain

1) Vegetation (from Gleason and Cronquist,1963)

Division Pteridophyta

Order Equisetales

Family Equisetaceae

Species *Equisetum arvense* L.

Equisetum hyemale L.

Order Filicales

Family Osmundaceae

Species *Osmunda regalis* L.

Family Polypodiaceae

Species *Adiantum pedatum* L.

Athyrium filix-femina (L.) Roth.

Athyrium thelypteroides (Michx.) Desv.

Onoclea sensibilis L.

Polystichum acrostichoides (Michx.) Schott.

Pteridium aquilinum (L.) Kuhn.

Division Spermatophyta

Class Gymnospermae

Order Coniferae

Family Pinaceae

Species *Picea glauca* (Moench) Voss.

Pinus resinosa Ait.

Pinus strobus L.

* *Pinus sylvestris* L.

Class Angiospermae

Subclass Monocotyledoneae

Family Araceae

Species *Arisaema triphyllum* (L.) Schott.

Symplocarpus foetidus (L.) Nutt.

Family Liliaceae

Species *Maianthemum canadense* Desf.

Polygonatum biflorum (Walt.) Ell.

Smilacina racemosa (L.) Desf.

Smilax rotundifolia L.

Smilax tamnoides L.var.hispida (Muhl) Fern.

Trillium grandiflorum (Michx.) Salisb.

Subclass Dicotyledoneae

Family Aceraceae

Species *Acer negundo* L.

Acer nigrum Michx.

Acer rubrum L.

Acer saccharinum L.

Acer saccharum Marsh.

Family Amaranthaceae

Species * *Amaranthus retroflexus*

Family Anacardiaceae

Species *Rhus radicans* L.

Rhus typhina L.

Family Apocynaceae

Species Apocynum androsaemifolium L.

Family Araliaceae

Species Panax quinquefolium L.

Panax trifolium L.

Family Asclepiadaceae

Species Asclepias syriaca L.

Family Balsaminaceae

Species Impatiens capensis Meerb.

Family Betulaceae

Species Betula lutea Michx.

Carpinus caroliniana Walt.

Ostrya virginiana (Mill.) K.Koch.

Family Caprifoliaceae

Species Sambucus canadensis L.

Triosteum perfoliatum L.

Viburnum acerifolium L.

Viburnum lentago L.

Family Caryophyllaceae

Species * Cerastium vulgatum L.

* Saponaria officinalis L.

* Stellaria media (L.) Cyrill.

Family Chenopodiaceae

Species * Chenopodium album L.

Family Compositae

Species Ambrosia artemisiifolia L.

* Arctium minus Schk.

Aster sp

Aster dumosus L.

Aster lateriflorus (L.) Britt.

Aster lowrieanus Porter.

Aster patens Ait.

Aster puniceus L.

Bidens frondosa L.

* Chrysanthemum leucanthemum L.

Cirsium discolor (Muhl.) Spreng.

Cirsium muticum Michx.

* Cirsium vulgare (Savi) Tenore.

Conyza canadensis (L.) Cronq.

* Crepis capillaris (L.) Wallr.

Erigeron annuus (L.) Pers.

Erigeron philadelphicus L.

Eupatorium maculatum L.

Eupatorium perfoliatum L.

* Hieracium pratense Tausch.

* Lactuca serriola L.

* Senecio vulgaris L.

Solidago sp

Solidago bootii Hook.

Solidago caesia L.

Solidago canadensis L.

Solidago flexicaulis L.

Solidago graminifolia (L.) Salisb.

Solidago nemoralis Ait.

Solidago patula Muhl.

Solidago remota (Greene) Friesner.

* Sonchus oleraceus L.

* Taraxacum officinale Weber.

Family Convolvulaceae

Species * Convolvulus arvensis L.

Family Cornaceae

Species Cornus florida L.

Cornus racemosa Lam.

Cornus stolonifera Michx.

Nyssa sylvatica Marsh.

Family Crassulaceae

Species * Sedum telephium L.

Family Cruciferae

Species * Alliaria officinalis Andrz.

* Capsella bursa-pastoris (L.) Medic.

Lepidium virginicum L.

Rorippa islandica (Oeder) Borbas.

Family Cucurbitaceae

Species Echinocystis lobata (Michx.) T.and G.

Family Ericaceae

Species Chimaphila umbellata (L.) Bart.

Pyrola sp

Vaccinium angustifolium Ait.

Family Fabaceae

Species *Apios americana* Medic.

* *Coronilla varia* L.

Desmodium canescens (L.) DC.

Lathyrus palustris L.

* *Medicago lupulina* L.

* *Melilotus alba* Desr.

Phaseolus polystachios (L.) BSP.

Robinia pseudoacacia L.

* *Trifolium pratense* L.

* *Trifolium repens* L.

Vicia cracca L.

Family Fagaceae

Species *Fagus grandifolia* Ehrh.

Quercus alba L.

Quercus rubra L.

Quercus velutina Lam.

Family Geraniaceae

Species *Geranium maculatum* L.

Geranium robertianum L.

Family Hamamelidaceae

Species *Hamamelis virginiana* L.

Family Hypericaceae

Species *Hypericum mutilum* L.

* *Hypericum perforatum* L.

Family Juglandaceae

Species *Carya cordiformis* (Wang.) K.Koch.

Carya ovata (Mill.) K.Koch.

Juglans nigra L.

Family Labiatae

Species *Collinsonia canadensis* L.

Lycopus sp

Mentha arvensis L.

* *Mentha piperita* L.

Monarda fistulosa L.

* *Prunella vulgaris* L.

Scutellaria galericulata L.

Scutellaria lateriflora L.

Family Lauraceae

Species *Lindera benzoin* (L.) Blume.

Sassafras albidum (Nutt.) Nees.

Family Lobeliaceae

Species *Lobelia inflata* L.

Family Oleaceae

Species *Fraxinus americana* L.

Fraxinus nigra Marsh.

Family Onagraceae

Species *Circaea quadrisulcata* (maxim.) Franch.and Sav.

Epilobium angustifolium L.

Epilobium coloratum Biehler.

Epilobium glandulosum Lehm.

Family Oxalidaceae

Species <u>Oxalis stricta</u> L.

Family Phrymaceae

Species <u>Phryma leptostachya</u> L.

Family Plantaginaceae

Species * <u>Plantago lanceolata</u> L.

* <u>Plantago major</u> L.

Family Polygonaceae

Species # <u>Polygonum aviculare</u> L.

<u>Polygonum lapathifolium</u> L.

* <u>Polygonum persicaria</u> L.

<u>Polygonum scandens</u> L.

* <u>Rumex acetosella</u> L.

* <u>Rumex crispus</u> L.

Family Primulaceae

Species <u>Oenothera biennis</u> L.

<u>Trientalis borealis</u> Raf.

Family Ranunculaceae

Species <u>Actaea alba</u> (L.) Mill.

<u>Hepatica acutiloba</u> DC.

<u>Hepatica americana</u> (DC.) Ker.

<u>Thalictrum dioicum</u> L.

<u>Thalictrum polygamum</u> Muhl.

Family Rosaceae

Species <u>Agrimonia</u> sp

<u>Amelanchier</u> sp

Crataegus sp

Fragaria virginiana Duchesne.

Geum sp

Geum canadense Jacq.

Geum virginianum L.

Physocarpus opulifolius (L.) Maxim.

* Potentilla recta L.

Potentilla simplex Michx.

* Prunus avium L.

Prunus serotina Ehrh.

Prunus virginiana L.

* Pyrus malus L.

* Rosa multiflora Thunb.

Rubus allegheniensis Porter.

Rubus flagellaris L.

Rubus hispidus L.

Rubus idaeus (var.strigosus)(Michx.) Maxim.

Rubus occidentalis L.

Rubus pubescens Raf.

Spiraea latifolia (Ait.) Borkh.

Family Rubiaceae

Species Galium aparine L.

Galium asprellum Michx.

Galium circaezans Michx.

Galium triflorum Michx.

Mitchella repens L.

Family Salicaceae

Species *Populus tremuloides* Michx.

Populus grandidentata Michx.

Salix sp

Family Saxifragaceae

Species *Mitella diphylla* L.

Ribes cynobasti L.

Family Scrophulariaceae

Species *Gerardia tenuifolia* Vahl.

* *Linaria vulgaris* Hill.

Mimulus ringens L.

* *Veronica serpyllifolia* L.

Family Solanaceae

Species *Datura stramonium* L.

* *Solanum dulcamara* L.

Family Staphyleaceae

Species *Euonymus obovatus* Nutt.

Family Tiliaceae

Species *Tilia americana* L.

Family Ulmaceae

Species *Ulmus americana* L.

Ulmus rubra Muhl.

Family Umbelliferae

Species *Cryptotaenia canadensis* (L.) DC.

* *Daucus carota* L.

Hydrocotyle americana L.

Osmorhiza claytoni (Michx.) Clarke.

Family Urticaceae

Species _Boehmeria cylindrica_ (L.) Sw.

Pilea pumila (L.) Gray.

* _Urtica dioica_ L.

Urtica dioica var.procera (Muhl.) Wedd.

Family Verbenaceae

Species _Verbena hastata_ L.

Family Violaceae

Species _Viola eriocarpa_ Schw.

Viola pubescens Ait.

Viola papilionaceae Pursh.

Viola septentrionalis Greene.

Family Vitaceae

Species _Parthenocissus vitaceae_ (Knerr.) Hitchc.

Vitis riparia Michx.

2) _Isopods_ (from Judd,1965; Barnes,1984)

Division Crustacea

Order Isopoda

Family Ligiidae

Species _Ligidium longicaudatum_ (Stoller)

Family Oniscidae

Species * _Oniscus asellus_ L.

* _Tracheoniscus rathkei_ Brandt

Family Trichoniscidae

Species *Trichoniscus demivirgo* Blake